PB-233 894

A STUDY OF THE EFFECTS OF LOW LEVELS OF CARBON MONOXIDE UPON HUMANS PERFORMING DRIVING TASKS

Harvard School of Public Health

PREPARED FOR
Coordinating Research Council, Incorporated

15 May 1973

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BIBLIOGRAPHIC DATA SHEET

1. Report No. CRC-APRAC-CAPM-9-69-2

2.

PB 233 894

4. Title and Subtitle
A Study of the Effects of Low Levels of Carbon Monoxide upon Humans Performing Driving Tasks

5. Report Date
May 15, 1973

6.

7. Author(s) R.A. McFarland; W.H. Forbes; H.W. Stoudt; J.D. Dougherty; T.J. Crowley; R.C. Moore; T.J. Nalwalk

8. Performing Organization Rept. No.

9. Performing Organization Name and Address
Guggenheim Center for Aerospace Health and Safety
Harvard School of Public Health
665 Huntington Avenue
Boston, Massachusetts 02115

10. Project/Task/Work Unit No.
CRC-APRAC-CAPM-9

11. Contract/Grant No.

12. Sponsoring Organization Name and Address
Coordinating Research Council, Inc., 30 Rockefeller Plaza, New York, N.Y. 10020 and Environmental Protection Agency, Durham, North Carolina 27709

13. Type of Report & Period Covered
Final -- 6/15/70-9/15/72

14.

15. Supplementary Notes
Not releasable to the public until July 1974.

16. Abstracts
This research was to determine the effects of low levels of carbon monoxide on human performance in driving-related laboratory tasks and in over-the-road vehicle driving. Twenty-seven subjects ranging in age from 20 to 50 years participated in these experiments under conditions of 17% COHb, 11% COHb, and "Control," or no-administered CO. The laboratory tests measured: (1) Complex psychomotor reactions involving simultaneous performance of a primary and secondary task; (2) dark adaptation and glare recovery; (3) peripheral vision; and (4) depth perception. The driving task was designed to evaluate driver visual information needs and the steering wheel movements required to keep a vehicle properly positioned within the driving lane at different speeds.

17. Key Words and Document Analysis. 17a. Descriptors
Carbon Monoxide
Carboxyhemoglobin
Vehicles
Traffic Safety
Occlusion
Peripheral Vision
Depth Perception
Air Pollution

17b. Identifiers/Open-Ended Terms
London, England
Boston, Massachusetts

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INFORMATION SERVICE
U S Department of Commerce
Springfield VA 22151

17c. COSATI Field/Group 7B;13B; 6K; 13B; 5J; 6P.

18. Availability Statement
Releasable to the general public.

19. Security Class (This Report)
UNCLASSIFIED

20. Security Class (This Page
UNCLASSIFIED

21. No. of Pages
100

22. Price
$ 4.00

FORM NTIS-35 (REV. 3-72)

THIS FORM MAY BE REPRODUCED

USCOMM-DC 14952-P72

A STUDY OF THE EFFECTS OF LOW LEVELS OF CARBON MONOXIDE UPON HUMANS PERFORMING DRIVING TASKS

CRC-APRAC Contract CAPM-9-69(2-70)

June 15, 1970 - September 15, 1972

Final Report

Prepared for the Coordinating Research Council, Inc., 30 Rockefeller Plaza, New York, New York, and the Environmental Protection Agency, Durham, North Carolina.

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FOREWORD

This project has been sponsored by the Coordinating Research Council, 30 Rockefeller Plaza, New York, N. Y. and the Environmental Protection Agency, Durham, North Carolina. The Air Pollution Research Advisory Committee of the CRC appointed a Technical Advisory Group in cooperation with EPA to assist in carrying out the research program.

First of all, our thanks are due to Mr. Milton K. McLeod, Secretary and General Manager of the Coordinating Research Council, and to Mr. Alan E. Zengel, Project Manager of the Council. Other members of the advisory group who aided us greatly in this study included Dr. John H. Knelson and Dr. D. W. C. Nelson of the Environmental Protection Agency (formerly the National Air Pollution Control Administration, Mr. Fletcher N. Platt of the Ford Motor Company, Mr. Joseph M. Collucci of the General Motors Corporation, and Dr. Wayne Stewart of the Sun Oil Company. On four different occasions this group spent from one to two days at the Guggenheim Center to review the progress being made and to make constructive criticisms about the research. These suggestions were of special value because of the wide experience and freedom from bias of the advisors. At no time was there any attempt to influence the outcome or results of the investigation.

In the early stages of the project we were fortunate in having the assistance of Mr. C. W. Dietrich, of Bolt, Beranek and Newman, Inc. Mr. Dietrich had previously carried out a study with an instrumented car, using the Visual Interruption Apparatus. He was able to assist in making the appropriate installations of the equipment, and in advising our engineers in designing certain improvements. Later, we had the valuable advice of Dr. Thomas Triggs, also of Bolt, Beranek, and Newman, during the road-test phase of our project.

One of the most difficult phases of the project related to having the subjects inhale the desired percentages of carbon monoxide mixtures so as to reach and maintain the desired carboxyhemoglobin levels over fairly prolonged periods of time. Also, it was necessary to make frequent and accurate determinations of the levels of carbon monoxide in the blood. We were fortunate in having the technical assistance of the late Professor F. J. W. Roughton of Cambridge University, England, an international authority in the field of hemoglobin. In collaboration with Dr. W. H. Forbes the biochemical aspects of the project were performed with great care and accuracy.

This project was carried out chiefly during the period June 15, 1970 - September 15, 1972. The early stages of the work related primarily to standardizing the laboratory tests and procedures, and instrumenting the car. Actually the final testing program continued until January 1, 1973. The analysis of the data was completed during the next four months.

During the first year, two-thirds of the funding for the project was furnished by the Coordinating Research Council, and one-third by the National Air Pollution Control Administration of HEW - now the Environmental Protection Agency. For the second year of the research, funding was reduced by one third, limited to that available from the Coordinating Research Council alone. This was because contractual negotiations for the second year between Harvard University and the Environmental Protection Agency reached an impasse over certain items in the contract with the new agency. The most important objection was a "technical direction" clause which was unacceptable to the University. This reduction in the budget for the second year resulted in our being able to test considerably fewer subjects than originally planned in both the laboratory and over-the-road testing programs.

Special acknowledgement should be made to **Anthony J. Morandi, M. A.** for his assistance in helping to develop some of the laboratory tests in the early phases prior to his leaving the project to take a position at Stanford University.

The recruiting and scheduling of subjects who had passed the physical examination and who could give enough time to the rigorous scheduling was a difficult task. This was ably done by Bonnie Myers, Sharon Greene, and Toula Coules. Mrs. Myers and Mrs. Greene also assisted in carrying out parts of the testing program in a competent way. Miss Coules is deserving of special credit for typing the manuscript and tables so capably. Mr. Richard Nardone provided essential technical assistance in regard to equipment and and testing procedures, especially with the automobile.

Finally, it is of interest to report that subsequently a study was undertaken on the effects of marihuana on driving, under the direction of **Dr. John D. Dougherty**, of the Guggenheim Center through support from the National Institute of Mental Health of HEW. In this investigation, the effects of marihuana were studied separately, as well as in combination with small amounts of carbon monoxide or alcohol. Although the same laboratory tests were given, a different procedure was used in the over-the-road driving tests. Where carbon monoxide alone was used, significant effects on the Complex Coordination Test were obtained with somewhat smaller amounts of CO than reported in the original study, although generally the results were similar.

May, 15, 1973

Ross A. McFarland
Project Director

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Summary

The purpose of this research was to determine the effects of low levels of carbon monoxide on human performance in driving-related laboratory tasks and in over-the-road vehicle driving. Twenty-seven subjects ranging in age from 20 to 50 years participated in these experiments under conditions of 17% COHb, 11% COHb, and "Control", or no-administered CO. The laboratory tests measured: (1) Complex psychomotor reactions involving simultaneous performance of a primary and secondary task; (2) dark adaptation and glare recovery; (3) peripheral vision; and (4) depth perception. The driving task was designed to evaluate driver visual information needs and the steering wheel movements required to keep a vehicle properly positioned within the driving lane at different speeds.

The CO administration and COHb monitoring phase of the study demonstrated considerable intersubject variability both in CO retention and in the rate of CO uptake. The latter may be inversely related to age. Rates of CO elimination in air and in oxygen also showed considerable variability between subjects.

Results of the laboratory tests are as follows: For the central and peripheral complex task the subject responded to red or green lights presented in his central field of vision by pressing foot switches, and concurrently responded to any one of six lights which might come on in his peripheral field by pressing appropriate finger buttons. When the numbers of correct, incorrect and omitted responses on the central task were compared, no significant differences were found between CO and control conditions, except for a suggestion of more incorrect responses with CO with minimal prior test experience. Thus it is possible that a deleterious CO effect would be most apparent during the learning period, or during unfamiliar situations. COHb levels of 11% and 17% showed no effect whatever on central task reaction times.

When the peripheral task is considered, the overall numbers of correct, incorrect and omitted responses showed no CO-related differences, though there was a finding of greater variability with CO at one level. The relationship of the location of the peripheral stimuli, i.e., 15°, 30° or 45° from center to numbers of incorrect or missing responses showed no consistent pattern suggesting a general effect from CO, but there was an increase in omitted responses at 30° out from center on one side at both levels.

Response blocks, or attentional lapses or gaps in performance, appear to have a CO-related effect of marginal statistical significance. It does appear that more subjects showed response blocking at both CO levels than under the control condition.

If the possible effects of CO on interactions between the central and peripheral tasks are considered, we find that peripheral responses are more frequently omitted at 17% COHb, but less markedly at 11%, if their stimuli

appear close in time to a central stimulus. This may be a normal tendency which is enhanced by exposure to CO. When response times to peripheral stimuli are considered, there appears to be a tendency to longer reaction times when the stimuli are close to a central stimulus, but here a close CO effect is not apparent. Nor did the frequency of excessively long response times appear to be related significantly to CO.

When final dark adaptation threshold values obtained on different days from the 17% COHb, 11% COHb and Control sessions are compared, no significant differences were found. However, when intraday pretest (before gassing) results were compared with post-gassing 17% COHb and control results, both showed statistically significant differences in the direction of more light needed during the test than the pretest. The direction of change was the same for 11% COHb test-pretest, though the difference was not significant. Comparisons at other time points on the dark adaptation curve, i.e., at 1, 4, and 10 minutes showed a generally similar pattern of pretest-test differences. However, since the control (or placebo) session produces results which parallel those of the CO sessions, there is a strong suggestion that the gassing procedure itself, and not the resulting COHb, is producing these effects. Glare recovery time showed no significant CO-related differences.

On a test of peripheral vision subjects missed significantly more targets presented at 20° from their central fixation point with 17% COHb than under Control conditions. They also missed more at 11% though the difference was not statistically significant. There does appear to be a CO-related decrement in peripheral vision here, though the extent of the data does not permit firm conclusions in this regard.

No differences whatever were found between measures of depth perception with a standard Verhoeff apparatus at COHb levels of 11%, 17%, and Control.

For the driving phase of the study a test vehicle was equipped with a Visual Interruption Apparatus for evaluating driver attentional demands and information processing, as well as with a potentiometer for measuring steering wheel movements. With the visual interruption apparatus the driver's vision was normally occluded by a visor until he pressed a foot switch giving him a 0.5 second "look". When occluded distances travelled on standardized runs were compared for CO (17% COHb) and no-CO conditions, no statistically significant differences were found at either 30 or 50 mph, i.e., drivers were demanding no more, nor less, visual input with CO than without it. It was also observed that at 50 mph the percentage of occlusion time was always less (i.e., the driver needed more visual information) than at 30 mph. This held true for both CO and control conditions, but with CO the subjects required relatively more roadway viewing at the higher speed than they did without CO. This CO-related effect was statistically significant.

Analysis of steering wheel reversals standardized for roadway distance and for time indicated only negligible changes associated with the administration of CO, intra- and intersubject variability being the most significant factor. Thus 17% COHb was found to have no significant effect on steering wheel reversals.

I. Introduction: Statement of the Problem

The purpose of the present investigation was to study the effects of small amounts of carbon monoxide on human performance in driving-related tasks in the laboratory, and in vehicle driving over the road. The first phase of the study involved the utilization of laboratory tests. The procedures developed and employed in this program are those believed most likely to influence the visual reactions and control responses of the driver.

One of the major problems in studying the effects of carbon monoxide on driving performance relates to the development of sensitive tests. Many of the studies previously carried out by others have been handicapped by the fact that the effects of CO on the subject could have been concealed by exerting greater effort, or by failure to control for practice effects or learning. In our studies of the effects of altitude, carbon monoxide and of other agents in the environment, we have developed techniques which have proved to be reliable and effective in measuring threshold values. These have included sensory tests of visual perception and tests of mental performance and information processing. During the first year of the study, considerable effort was expended on the design of the laboratory experiments and the fabrication of the equipment. After all of the experimental designs were finalized and all laboratory systems were operational, data were obtained on twenty-seven subjects in the laboratory phase of the project.

The second phase of the study involved over-the-road driving experiments with an automobile especially designed for this experiment at the Harvard School of Public Health with assistance from its subcontractor, Bolt, Beranek and Newman, Inc., of Cambridge, Massachusetts. Experimental protocols utilizing a Visual Interruption Apparatus were developed. Each phase of the research program, including CO administration and monitoring, laboratory testing, and driving experiments, are described in detail below.

A. Implications from Biostatistical Studies of Accidents

It has been brought out repeatedly that automobile accidents are non-repetitive in nature, with non-specific causation and usually resulting from multiple causes. It is well known from biostatistical studies that youthful age, lack of training and experience, changes in skill with advanced age, and use of alcohol or drugs are factors which frequently enter into the interactions between the driver, the vehicle, and the environment. It also has been observed frequently that the amount of illumination is an important factor and that high fatality rates tend to occur during twilight or at night. There may also be greater consumption of alcohol during these times of day. (McFarland and associates, 1972)

Although careful experimentation has not established the possible ways by which small amounts of carbon monoxide may influence driving performance, it might be assumed, however, that the effects of small amounts existing in city streets from automobiles might have a cumulative or synergistic effect in combination with other variables. For example, the role of carbon monoxide in impairing the uptake and delivery of oxygen to the tissues is very pronounced. In fact at body temperature, the hemoglobin molecule has an affinity for carbon monoxide about 210 times as great as that for oxygen. If a person has anemia, or has carbon monoxide in his blood from cigarette smoking, the small amounts from city streets might have more serious effects. It is also well known that the effects of alcohol impairs the transport of oxygen to the tissues. Also, there are many commonly used drugs which have similar effects. It would be unrealistic to assume, therefore, that drivers will be influenced by any one of the above possibilities, but more probably a number of them acting in combination. (McFarland, 1963, 1970)

B. Representative Exposures of Drivers to the Carbon Monoxide of City Traffic

It is very important to consider the amounts of carbon monoxide which might be found in city streets. Obviously this would be a function of atmospheric conditions and winds, as well as the back-up of traffic on congested streets or in peak traffic periods. Also, it may be some time before the improvement from the newer models with better control of engine exhaust will be apparent. Only a few examples can be reported here of the amount of carbon monoxide prevailing at present.

During April 1971 one of us had an opportunity to visit the Medical Research Council Air Pollution Unit at St. Bartholomew's Hospital Medical College in London. During the conference with the Director, Dr. P. J. Lawther, it was possible to obtain information in regard to their studies on carbon monoxide in the City of London. The variation in carbon monoxide in the blood of four subjects driving for four hours in heavy London traffic is shown in Figure 1. The average amount of carbon monoxide in the streets was reported to be 35 ppm. It is interesting to note the striking difference between non-smokers and smokers. (Lawther, 1970) Dr. Lawther reported that the more recent studies have been similar. Also, it is interesting to note that no impairment has been observed in a large number of psychophysical tests administered under conditions simulating the amounts of CO in London city streets.

One of our colleagues at the Harvard School of Public Health, Dr. Benjamin G. Ferris, Jr., has been carrying out a study relating to the amounts of carbon monoxide found in Boston policemen. In eighty subjects studied thus far, the highest value of COHb, 14.4%, was found in a policeman who inhaled cigar smoke over long periods of time. The next highest value was 12.6%, followed by a third at 10.5%. Almost all of the non-smokers had values of COHb below 4.0%, and most of the smokers below 6.0%.

Any study of the effects of carbon monoxide on driving performance should take into account the fact that chronic cigarette smokers tend to have from 4 to 8% carboxyhemoglobin in their blood. The importance of this fact has been

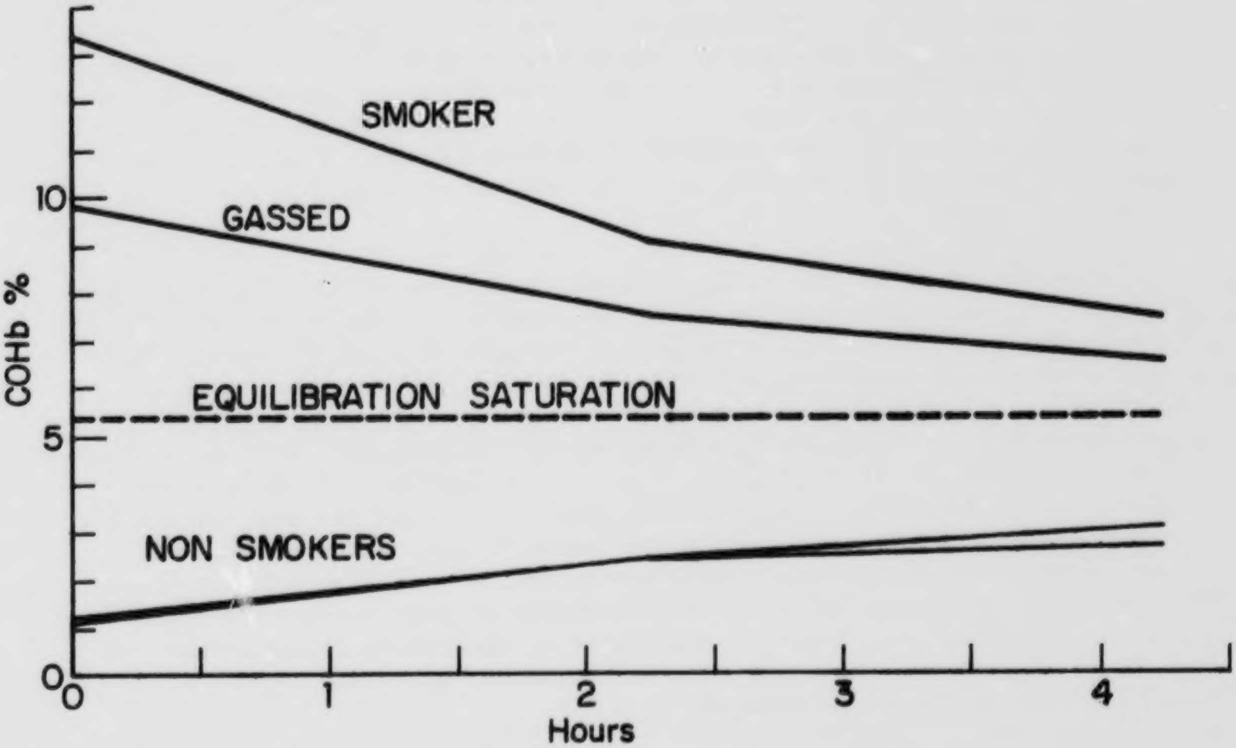

Figure 1. Variations in COHb % in four subjects during four hours driving in heavy London traffic; mean street CO approximated 35 ppm. The uppermost curve represents a smoker starting the experiment after smoking 17 cigarettes; the lower curve at the top represents a non-smoker "gassed" to the level shown at the start. (Lawther and Commins, 1970)

brought out in relation to the combined effects of carbon monoxide and altitude in pilots. The true physiological altitude of an airman would be related to the decreased amount of oxygen while in flight. Nomograms have been developed so as to show these combined relationships (McFarland, et al., 1944). These data were developed on the basis of the diminished ability to see targets at low levels of illumination with the dark adapted eye, along with the amount of carbon monoxide in the blood.

The effects of small amounts of carbon monoxide from smoking are demonstrated in Figure 2. Each subject studied was first brought in a chamber simulating high altitude to approximately 7,000 feet or higher, and the diminished ability to see was determined. After returning to sea level conditions, the subjects were then asked to inhale the smoke of three cigarettes. As shown in the top part of Figure 2, the effect of the saturation of the blood with CO (4.1% COHb) was equal to that of about 7,500 feet altitude. Therefore, the subject was at a physiological altitude of 7,500 feet while still at sea level. (McFarland, 1946)

In recent years an interesting problem has arisen in the building of highway tunnels at high altitude in the Rocky Mountains. For example, what would be the effects on drivers and passengers in the tunnels at 11,000 feet? Three possible sources of hypoxia would result as follows: (1) decreased partial pressures of oxygen due to elevation; (2) inhalation of CO from cigarette smoke; and (3) inhalation of CO discharged in motor vehicle exhaust. By means of the nomograms mentioned above and other data, the combined effects of altitude, smoking and tunnel CO were determined, and it was recommended that the CO concentration in the tunnel be maintained below 25 ppm, among a series of other recommendations in regard to smoking and the use of oxygen for engineering purposes. (Miranda, et al., 1967) It should be kept in mind that many parts of the United States have highways and cities at moderately high altitudes where the effects of carbon monoxide for non-acclimatized persons, both smokers and non-smokers, might be accentuated.

As indicated above, the amount of carbon monoxide resulting from automobile exhaust is of importance in relation to its possible effects on driving performance. In Figure 3 the percent of COHb in the blood is shown in relation to the percent and parts per million of CO in the atmosphere. (Forbes, 1970) It is obvious from this figure that the length of the exposure is of great importance in relation to the concentrations in the blood. Other variables relate to the amount of activity, as well as general physical condition of the subject. It can be determined from this figure that the amounts of carboxyhemoglobin which might accumulate in the blood of the average driver during short periods of time would be very small. Concentrations as high as 50 ppm have been observed only infrequently in city streets of the United States. A study of the amounts of carboxyhemoglobin in various segments of the population has recently been reported by Stewart (1972). To aid the reader in interpreting the various values, the relationships between the amount of CO in the atmosphere and the percent of CO in the blood (COHb) are shown in Appendix A.

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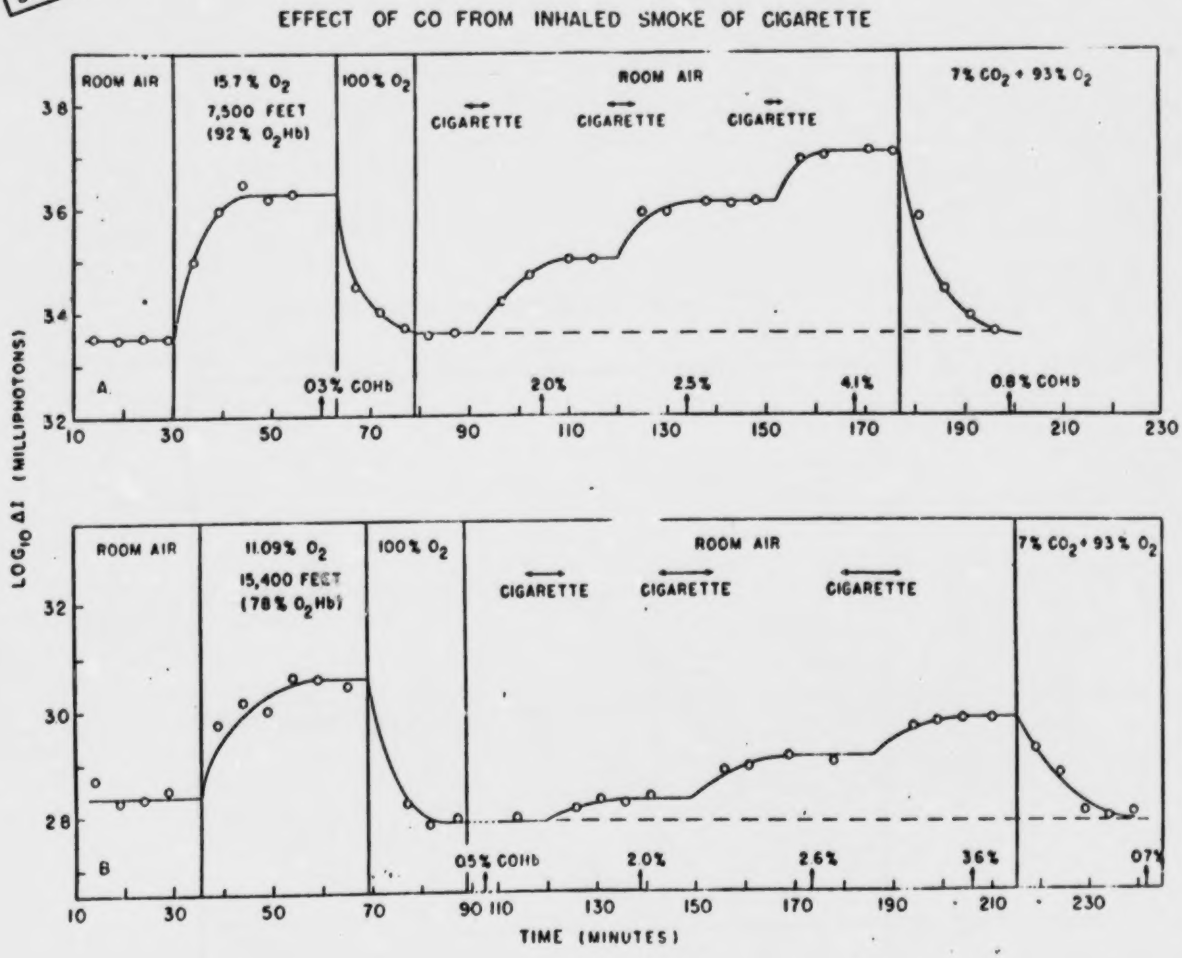


Figure 2. The effect of carbon monoxide from smoking on the light sensitivity of the eye is shown in comparison with that of high altitude for two subjects. (McFarland, 1963)

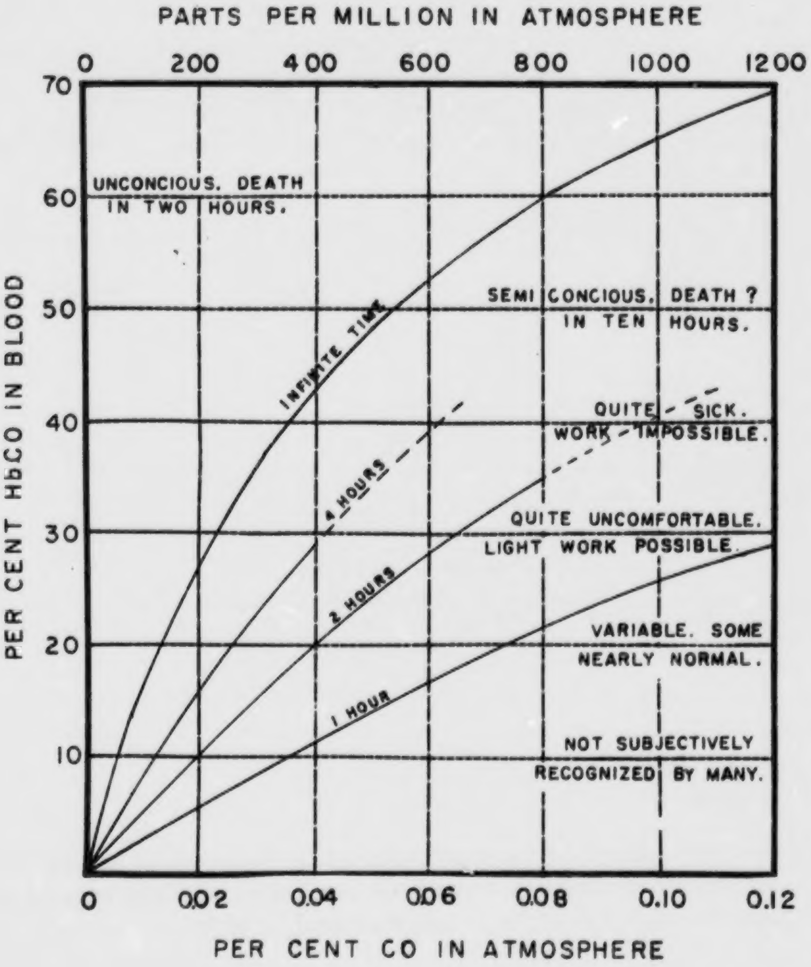


Figure 3. Percent COHb in blood vs. atmospheric CO at one, two, and four hours, and at infinite time. The effects of various percentages of COHb are given on the curves of percentage saturation. These are the effects expected if the individual is raised rapidly to the percentage COHb in question, and then maintained at that level. There are considerable variations, in persons in apparently good health, and the symptoms also vary from person to person, with headache the most common. (Forbes, 1970)

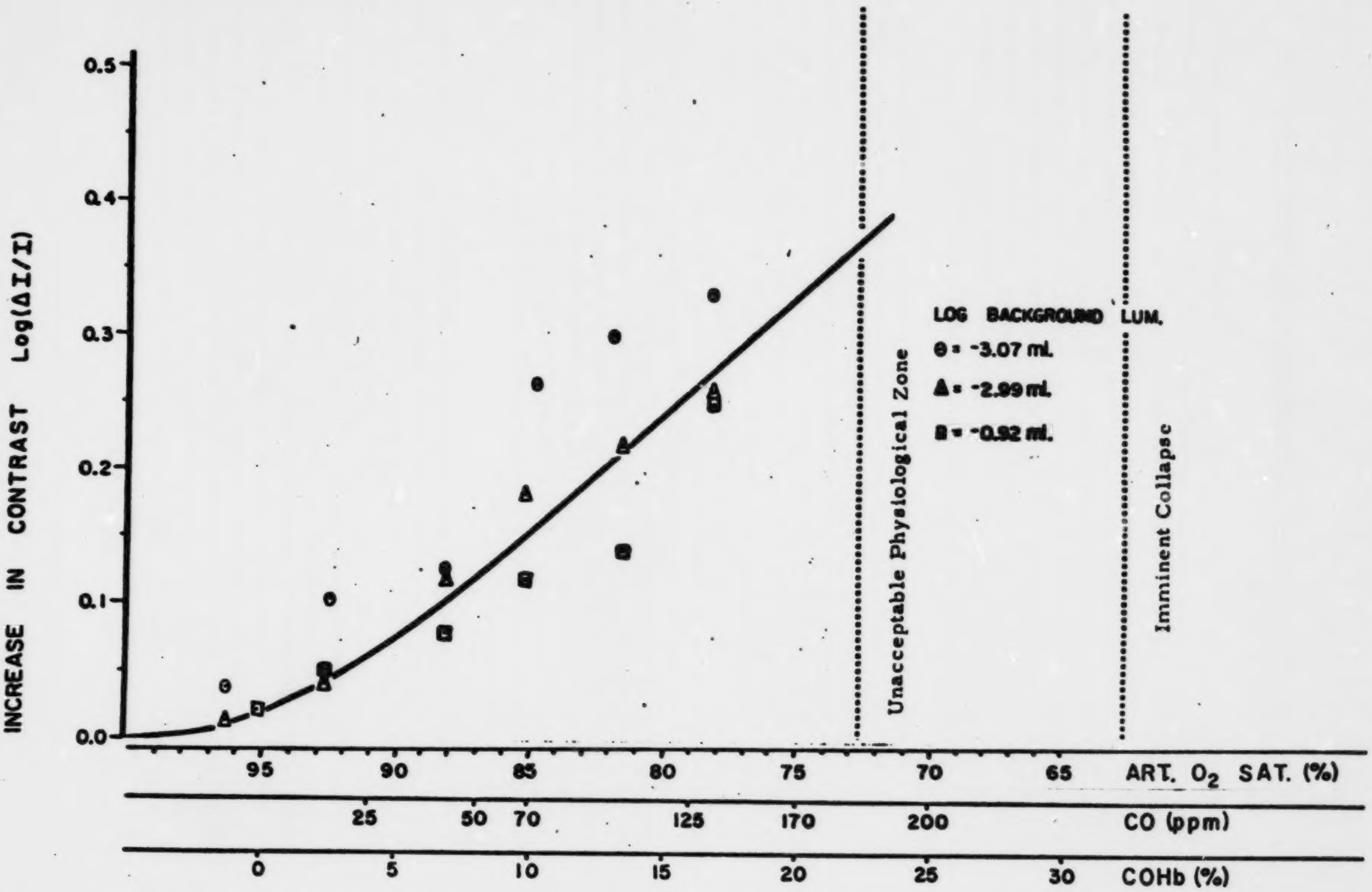
C. The Effects of Small Amounts of Carbon Monoxide on Human Performance

In our laboratory many studies have been carried out on the effects of lowered oxygen tension on the central nervous system whether produced by ascents to high altitude or by agents which impair the delivery of oxygen to the tissues, such as carbon monoxide. To obtain precise results relating to impairment, the tests should possess a high degree of sensitivity and be independent of conscious effort or learning on the part of the subjects. We have found that psychophysical tests of sensory functions, such as light sensitivity, have many of the desirable characteristics. Also it has been possible to devise other tests that detect and scale increased effort. In addition, measures of speed and accuracy can be combined into measures of rate of information processing and space or reserve capacity. (McFarland, 1970)

In this report it will be possible to review only a few of the studies which have been concerned with impaired oxidation in the nervous tissue. The visual tests selected were as follows: (1) visual acuity at low levels of illumination; (2) dark adaptation; and (3) differential brightness sensitivity. In studying the effects of high altitude it was found that sensitivity of the dark adapted eye was significantly impaired as low as 4,000-6,000 feet altitude. It was also observed that the effects of oxygen want were much greater at low levels of illumination. (McFarland, et al., 1941) Additional studies were carried out on the effects of small amounts of carbon monoxide. The above tests also proved to be very sensitive. Analysis showed a comparison of the effects of carbon monoxide and the reduced partial pressure of oxygen on the brightness thresholds. It is relevant to note that the increase in threshold or poorer performance was apparent at 5% COHb, or 25 ppm of carbon monoxide. In Figure 4, similar comparisons have been made in respect to the effects on visual contrast thresholds with various background luminances. This proved to be one of the most sensitive tests, and significant impairment resulted with highly trained subjects. (McFarland, et al., 1941, 1944)

Studies with other psychophysiological tests have shown that larger amounts of carbon monoxide or higher simulated altitudes were required to produce significant impairment. Neuromuscular coordination and pursuit tasks were influenced only in more advanced stages of oxygen want, with auditory acuity being most resistant to hypoxia. Certain cognitive functions such as immediate memory proved to be more vulnerable, the effects beginning at about 7,000 feet simulated altitude, or 5-8% COHb. It is interesting to note that one of the most sensitive tests of the effects of aging relates to diminished visual acuity at low levels of illumination, as well as loss of capacity for short-term memory. These results might be expected since it has been fairly well established that there is lowered oxidation in the nervous tissue in one form or another during the processes of aging. (McFarland, 1963) Other studies have been reported of the impairment which may result from small amounts of CO in selected cognitive functions. (Schulte, 1963)

Figure 4. Effects of hypoxia and carbon monoxide on contrast thresholds for targets with various background luminances. (Data from McFarland, Evans, and Halperin, 1941)



One of the most significant influences of reduced oxygen tension relates to the subject's capacity to receive and interpret information in the visual field such as in driving. There is a tendency for the central nervous system to respond in a less flexible manner. Ideas tend to persist, or perseverate, and there may even be a blocking of responses. These tendencies have been frequently observed in studies of oxygen want. One of the earlier ones brought out the important principle of "blocking" during hypoxia and mental fatigue. (Bills, 1937) This may be an important way of interpreting the accident potential relating to driving performance as Teichner has recently pointed out. Indeed, response blocking may be one of the most characteristic reactions which may occur during continuous, high-information processing tasks. It may be involuntary and subject to all of the factors which affect driving skill thus related to accident probabilities. (Teichner, 1968) In Figure 5 the effect of carbon monoxide on frequency of response blocking is shown as postulated from studies relating to impaired oxidation, whether from high altitude or carbon monoxide. Similar effects might be expected from loss of sleep, excessive alcohol, or various drugs.

D. Measurement of the Performance of Drivers on the Road

Experimental attempts to measure the performance of drivers while operating vehicles on the roadway have been quite limited in their extent. It is difficult to carry out controlled experiments with the driver's being aware of the measurement procedures and being influenced by them. Furthermore, the demands on the ability of the driver to process the incoming information vary greatly. At times the demands are considerably below his full capacity; at others this may be exceeded. Some of the needs for information relate to tasks in the immediate and ongoing control of his vehicle, for example, in relation to lane holding, maintaining distance from a leading car, steering, braking, or accelerating in relation to other traffic or roadway hazards. In addition the monitoring of dashboard instruments and of roadside directional and warning signs is necessary. Thus, one approach to the measurement of performance may be based on the information processing inherent in driving, utilizing the techniques of information theory.

In the context of automobile driving, one method has been concerned with measuring information processing as reflected in changes in performance on a subsidiary task such as mental arithmetic carried out while operating a vehicle under various conditions of traffic and roadway complexity. This method has been useful in demonstrating reductions in "spare mental capacity" as attentional and information processing increases with driving complexity.

Another approach utilizes a technique of intermittent visual time sampling. The field of view of the driver is interrupted systematically as he operates a vehicle on the roadway. This is accomplished by a helmet-mounted visor which alternately drops to occlude the driver's vision at controlled frequencies and duration. Initial experiments have been conducted on closed road systems and unopened sections of interstate highways. It was found that sufficient information

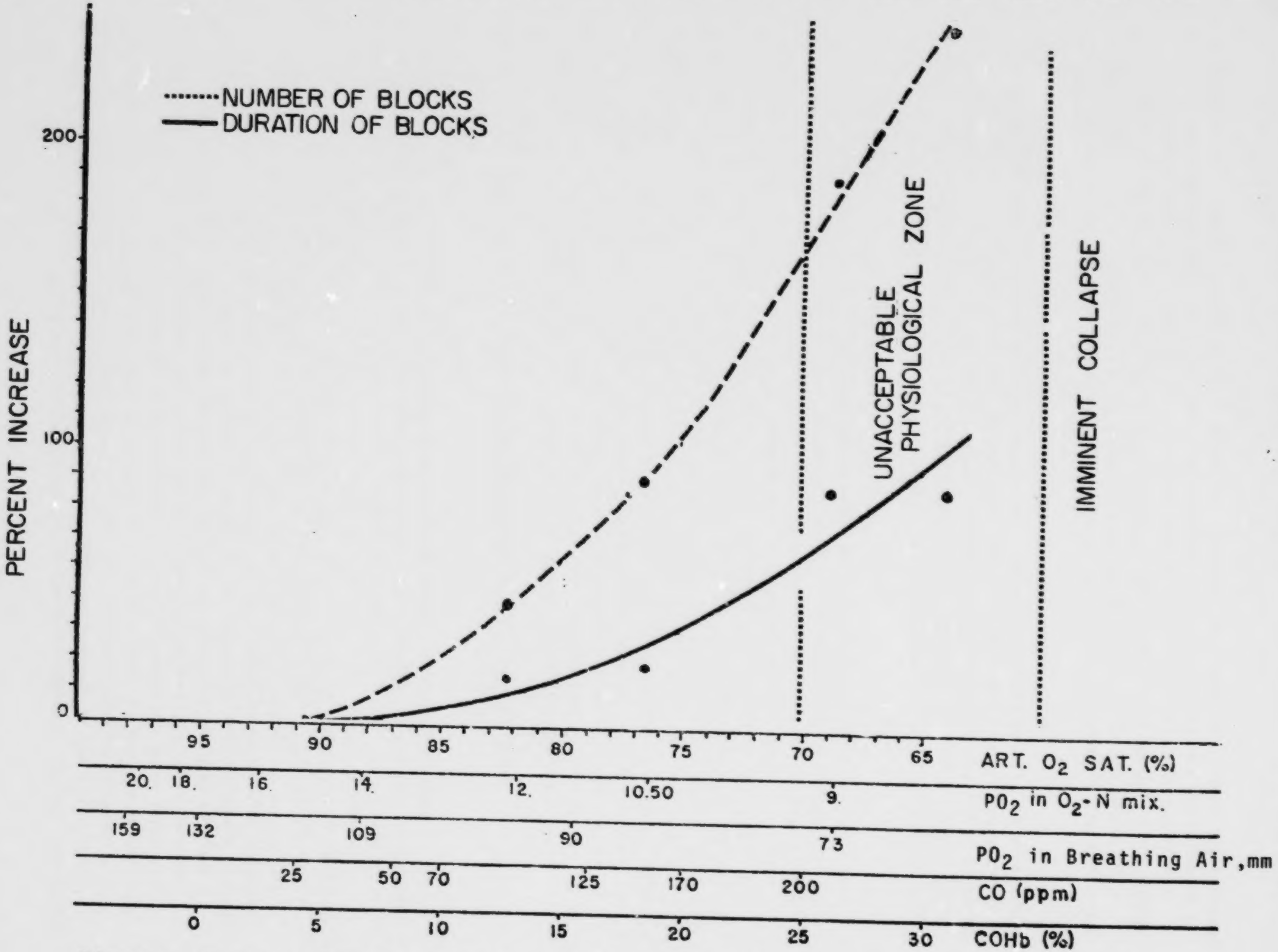


Figure 5. Expected effects of carbon monoxide on response blocking. (Teichner, 1968, adapted from McFarland, Evans, and Halperin, 1941; and Bill, 1937.)

for error-free lane holding operating was obtained if drivers viewed the road for a period of one-half second at two-second intervals at a speed of 60 mph at every four seconds at 25 mph, and every nine seconds at 5 mph. The records were obtained under conditions where (1) the occlusion rate was controlled by the experimenter and vehicle speed by the subject, and (2) where vehicle speed was controlled and the driver actuated the occlusion device as needed. The results were used to develop a mathematical model which related the driver's informational content of the roadway in "bits" per mile, the speed of the vehicle, and the driver's estimates of his own uncertainties. (Senders, et al., 1967) This work was subsequently extended to include the information-processing demands of car-following and passing, and driving under normal traffic conditions.

A second application of information theory relates to the recognition of signs and traffic control devices. Objective measures of recognizing a variety of roadside signs by subjects of different age and socio-economic status were obtained in experiments carried out on drivers wearing the vision interruption device described above. These data were related to the probabilities provided by signal detection theory in a way which resulted in an index of relative recognizability. Thus far no studies have been carried out with these techniques while drivers were being influenced by carbon monoxide. (Senders, et al., 1969)

II. Subject Selection and Medical Examination

The subjects for the laboratory phase of the present research ranged in age from 20 to 50 years, with the majority in their twenties. Both smokers and non-smokers were included, and although the sample was not stratified on the basis of smoking behavior, smoking histories were obtained on each subject for use in the data analysis. All subjects were paid $60 for participation in three laboratory sessions of about 4-5 hours duration each. Subjects were obtained through posted notices at the Harvard School of Public Health and Northeastern University, through the Massachusetts Employment Service, and through advertisements in the three major Boston newspapers. The total number of laboratory subjects was 27. Subjects for the driving phase were selected from those who have satisfactorily completed all of the laboratory work.

Medical selection of the subjects was carried out prior to the experiments. Before selection, questionnaires were used to obtain subjects who had no contraindications to the experimental hypoxia. (See Appendix B) This procedure ruled out individuals with a history of disease involving the neurological, cardiovascular, renal, hematopoetic or pulmonary systems. Subjects with a history of an allergic or toxic response to any drug or chemical were not accepted. Individuals with a history of any emotional disturbance which required treatment were also excluded. All subjects were initially tested for visual requirements with a Titmus Vision Tester in the laboratory. The medical examination included neurological and pulmonary function tests, chest x-ray and complete blood count and urinalysis, and an electrocardiographic examination, as well as a double Master's 2-step test for subjects over 39 years.

Normal standards were defined as equivalent to U.S. Air Force standards for entry into flight training except as follows: (1) Any subject with uncorrected visual acuity due to myopia or hyperopia which corrects to 20/20 was acceptable. (2) Hemoglobin must be greater than 14.5 gm/100 ml. (3) Vital capacity values must be 80% of predicted for height and age, and 1-second forced expiratory volume 70% of the total. (4) Sitting pulse rate must be less than 85 beats per minute. After 20 hops the pulse rate must not be greater than 120 beats per minute, and 2 minutes after exercise not greater than 100 beats per minute.

During the testing program no subject was allowed to continue exposure to CO if his symptoms warrant termination. In addition, CO exposure was terminated in the event of faintness, dizziness or apparent loss of gross mental function. At the end of their participation, all subjects underwent a second physical examination identical to the procedure used for initial selection. (See Appendix C for copy of consent form signed by all subjects.)

III. Carbon Monoxide Administration and Carboxyhemoglobin Monitoring

A. General Procedures

The procedures for the administration of carbon monoxide (CO) and for the monitoring of the carboxyhemoglobin (COHb) levels of each subject participating in the experiments were as follows: Immediately upon arriving at the laboratory the subject had both a blood sample and an alveolar (expired air) sample taken to determine his initial COHb levels. He was then seated comfortably, a nose clamp applied, and he breathed one of two gas mixtures through a mouthpiece (see Figure 6). Initially a face mask was used to administer the mixtures, but leakage around the face seal on many subjects necessitated a change to the mouthpiece, which though less comfortable and convenient, eliminated the problem of leaks.

Each subject breathed either normal room air for a control session in which his CO exposure was called "zero,"(that is, no CO was added), or an air mixture containing 720 ppm of CO. In either case the subjects breathed from a 500 liter Tissot gasometer and exhaled into a second one, so that by measuring the CO in a small sample from the second Tissot and knowing the content in the first Tissot, we could monitor the amount retained by the subject. There were differences in rate of uptake of around 15% or more between subjects, and variations within the same subject of as much as 10%, for reasons we believe were probably due to differences in "restlessness" during the period of exposure to the CO. The Tissot gasometer system is shown in Figure 6.

During the first set of experiments on 9 subjects, four different levels of exposure to CO were used, zero and enough to produce 6% COHb, 11% COHb, and 17% COHb. In practice it was difficult to achieve these figures precisely. Those of our subjects who were smokers came in with 2% to 6% COHb, and the non-smokers from 0.5% to 2%, so that anything under 4% COHb was used as our "zero" exposure. The varying rates of uptake even in the same individual also made it difficult to attain the 6, 11 and 17% goals so that we were sometimes over or under the desired saturation by 1% and occasionally 2% COHb, that is, in aiming at 17% we might be as high as 19% or as low as 15%. The exposure lasted 80 minutes since we were using only 720 ppm CO in the inspired air. However, if the subjects were low, they were given a short additional CO exposure to raise their level to about 17%. If high, the tests were run at this slightly higher level, as the subjects fell from 19% to 17% after 20 minutes of breathing air during the testing.

After the initial 80-minute exposure, blood and alveolar samples were obtained and COHb levels determined. The subject then completed one portion of the experimental tasks. At this time an alveolar sample was again taken, and the subject was re-exposed to the mixtures (room air or CO mixture) for a short period to regain the desired COHb level. Alveolar and blood samples were again taken and the subject completed the remainder of the experimental tasks. After another alveolar sample the subject was "washed out," i.e., had his COHb

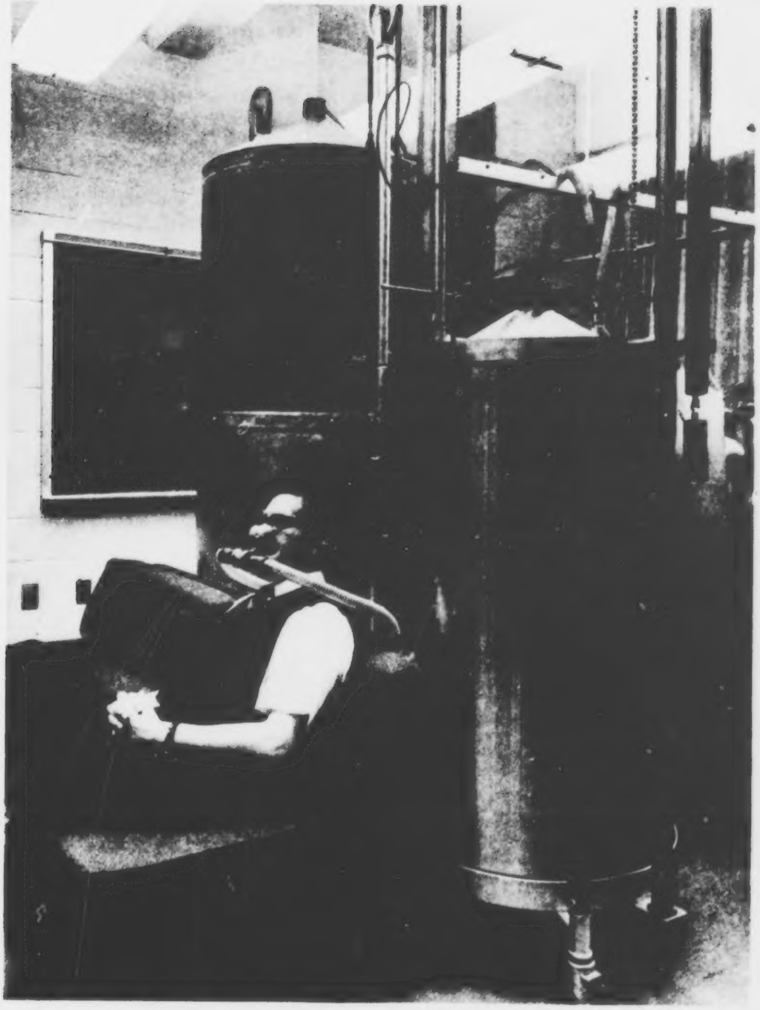


Figure 6. Subject breathing mixture from gasometer.

level reduced by breathing a mixture of 99% oxygen and 1% carbon dioxide for approximately 80 minutes. (See Figure 7.) No subject was released until his COHb level was below 6%. Final alveolar and blood samples were obtained to determine this level.

B. Equipment and Techniques

COHb levels were determined with a Model 182 CO-Oximeter (Instrumentation Laboratories). A 3 cc venous sample of blood was obtained: (a) upon arrival at the laboratory; (b) after inhalation of the CO mixture; (c) after re-exposure to the CO mixture, and (d) at the end of the session. Determinations were made twice with same sample which gave hemoglobin in grams/ml, oxyhemoglobin in grams percentage/ml, and carboxyhemoglobin in grams percentage/ml. The second determination was within plus or minus 0.2% of the first determination. Correlative curves have been made with COHb levels and alveolar (ppm) levels (see below).

The CO-Oximeter has proven to be reasonably reliable in determining the COHb levels used in this study. Scale linearity is well maintained throughout, except below 3% where the findings are more questionable. Maintenance of the instrument has presented problems, however, and it has been necessary to obtain three replacement instruments (under warranty) due to major component failures. In each case the instrument had to be returned to the manufacturer for repair and recalibration. The last of the three instruments was thoroughly satisfactory. A considerable amount of time was also expended establishing a set of techniques for the operation of the instrument that would provide the required level of accuracy.

A Beckman 315 AL Infrared CO Analyzer was used to determine the CO concentrations in air and alveolar samples, and in the room air. This instrument has three ranges of CO sensitivity, 0-100 ppm, 0-500 ppm, and 0-1000 ppm. This wide range of sensitivity is needed because of the diversity of CO concentrations in the air samples that must be tested by the equipment. These samples are: (1) the CO breathing mixture at 720 ppm CO; (2) air from the inspired air line, also at 720 ppm; (3) air from the expired air line at about 370 ppm; (4) total expired air, also about 370 ppm; (5) Douglas bag samples at 720 ppm; (6) alveolar samples, which may range from almost zero to 140 ppm; and, finally, (7) room air which may vary between 0-10 ppm.

The CO gas mixture was made up in a 600 liter gasometer, utilizing 380 cc of CO with 530 liters of air. This gave a standard mixture of 720 ppm which was used for all the COHb levels, with varying exposure times to the mixture used to obtain the different levels. It should be noted that all subjects were on the breathing apparatus for the same amount of time for all sessions. However, for the lower levels of COHb, the subjects breathed only room air for a portion of the time - a fact of which they were unaware. Figure 8 depicts an overall view of the gas apparatus including gasometers and Beckman Analyzer.

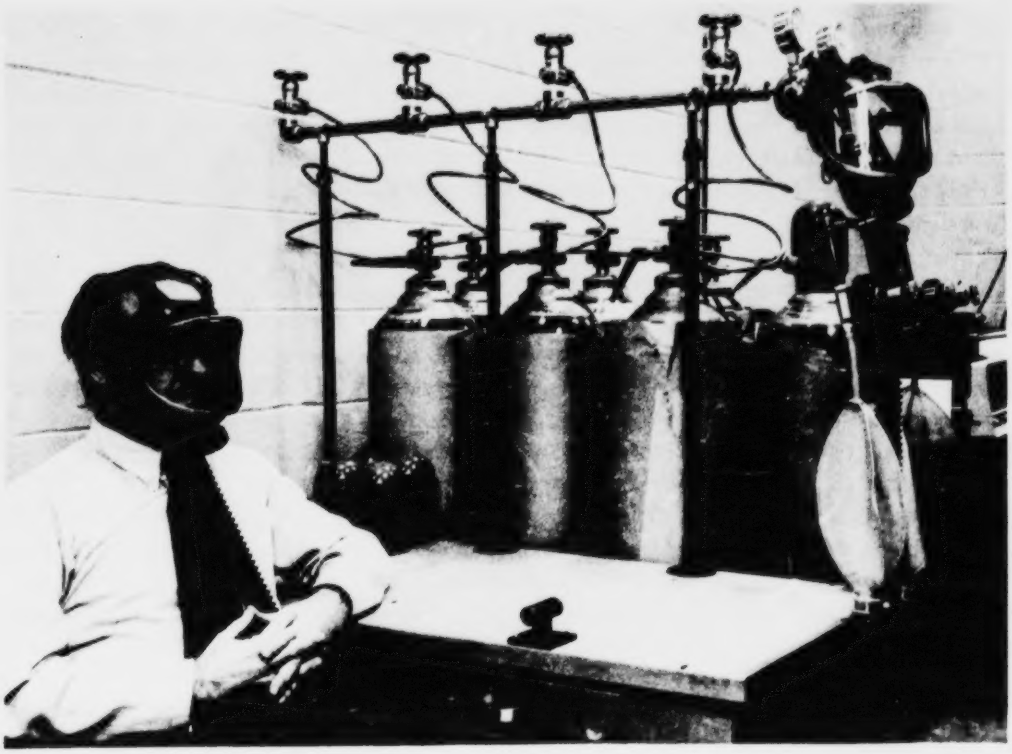


Figure 7. Subject "washing out" CO with 99% O_2 / 1% CO_2 mixture.

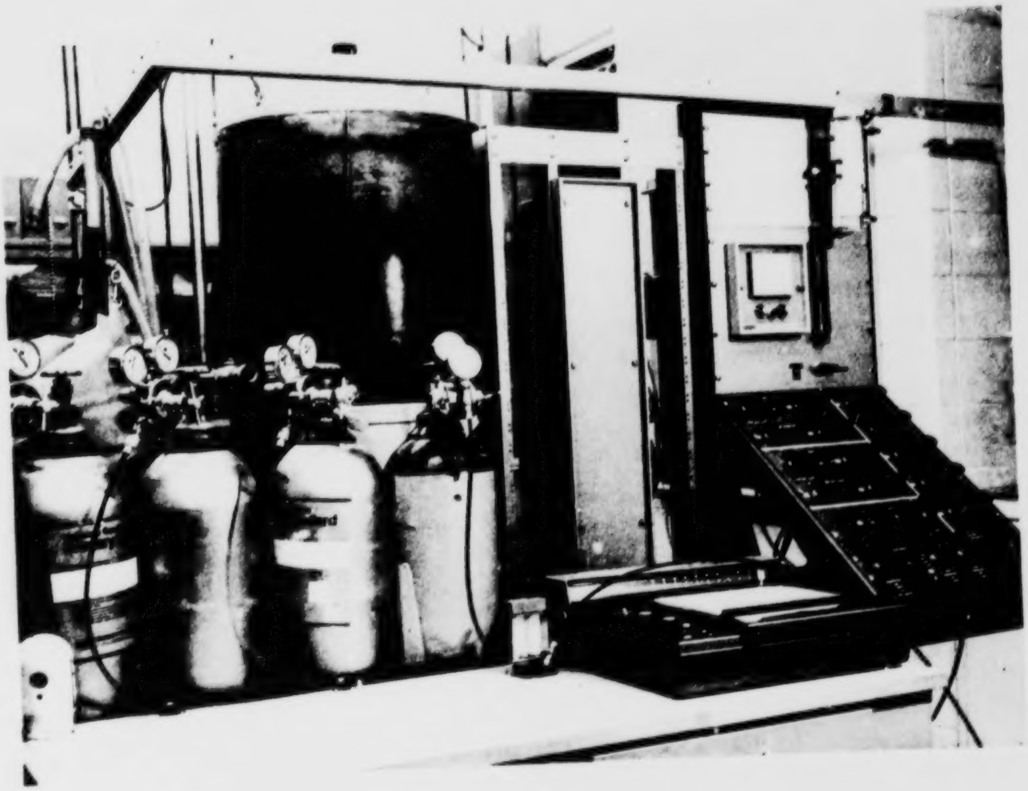


Figure 8. Gassing equipment including gasometer (rear), infrared analyzer, and control panel (right).

C. Alveolar CO Determinations

The accuracy of COHb determinations has improved with experience in operating the Instrumentation Laboratory's CO-Oximeter. The probable error in COHb is about ± 0.2%. At values below 3% COHb the accuracy appears to be decreased somewhat. In the alveolar samples the critical problem is to obtain an accurate sample of air from the subject. With experienced subjects the variations usually are not over 5 ppm which corresponds to 0.7% COHb. (See Figure 9.)

Figure 10 is typical of the rate of uptake and elimination of CO that we have obtained on our subjects. On these curves solid circles represent the values of percent COHb obtained by analysis of the blood. Open circles represent the values obtained by analysis of the alveolar air translated into percent saturation from a standard curve derived from the formula

$$\frac{\%\ \text{COHb}}{\%\text{O}_2\text{Hb}} = \frac{230\ \text{pCO}}{\text{arterial pO}_2}$$

and the assumptions that the arterial blood saturation is 98% and the arterial pO_2 is 98 mm. The values derived from the blood samples have been used in drawing the curves since they are more consistent than the alveolar samples, but the average discrepancy is under 0.7% saturation.

The line of small dots on the left of the higher curve in Figure 10 is the rate of uptake obtained in another experiment on the same subject at 720 ppm, the same exposure as in the solid curve. Although the elimination of CO in air and in oxygen actually follow logarithmic curves, as noted below, they are drawn here as straight lines, since intermediate measurements were not made.

The subjects showed considerable variation in the proportion of the inspired CO which they retained. This variation was apparent not only from subject to subject but also within the same subject on different exposures, and even within the same exposure, fluctuations were observed. The expired air was run continuously through the Beckman Analyzer, and the contents were thus observable, not breath by breath, but over 15 to 20 second periods, since the analyzer responded primarily to the air that had passed through it during the time period. Consequently a running integration was available of the values of the last 3 to 4 breaths.

The variations in these values were larger than expected. The retention was occasionally as low as 35% of the inhaled CO or as high as 55%. The average was 45%. The variations were quite irregular and were presumably due to the restlessness or boredom of the subjects. However, these variations were infrequent, and most of the time the subject retained from 42 to 48% of the inspired CO. These irregularities tend to even out over time so that the uptake appears to be regular and also linear within the limits of experimental error for periods of about one hour, or until about one-third of the final equilibrium

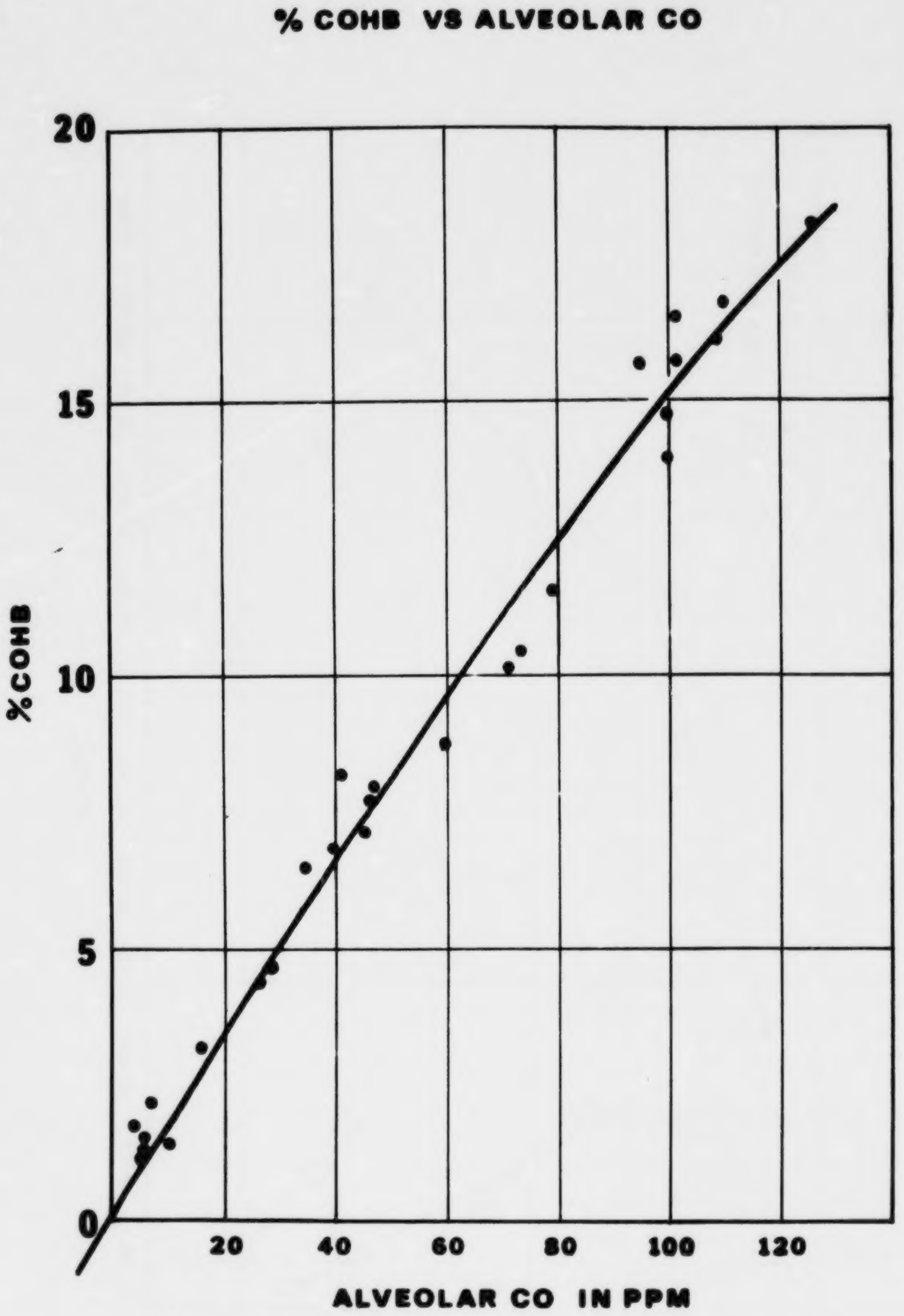


Figure 9. Percent COHb vs. alveolar CO in subjects from present study. Each dot represents one determination on a subject.

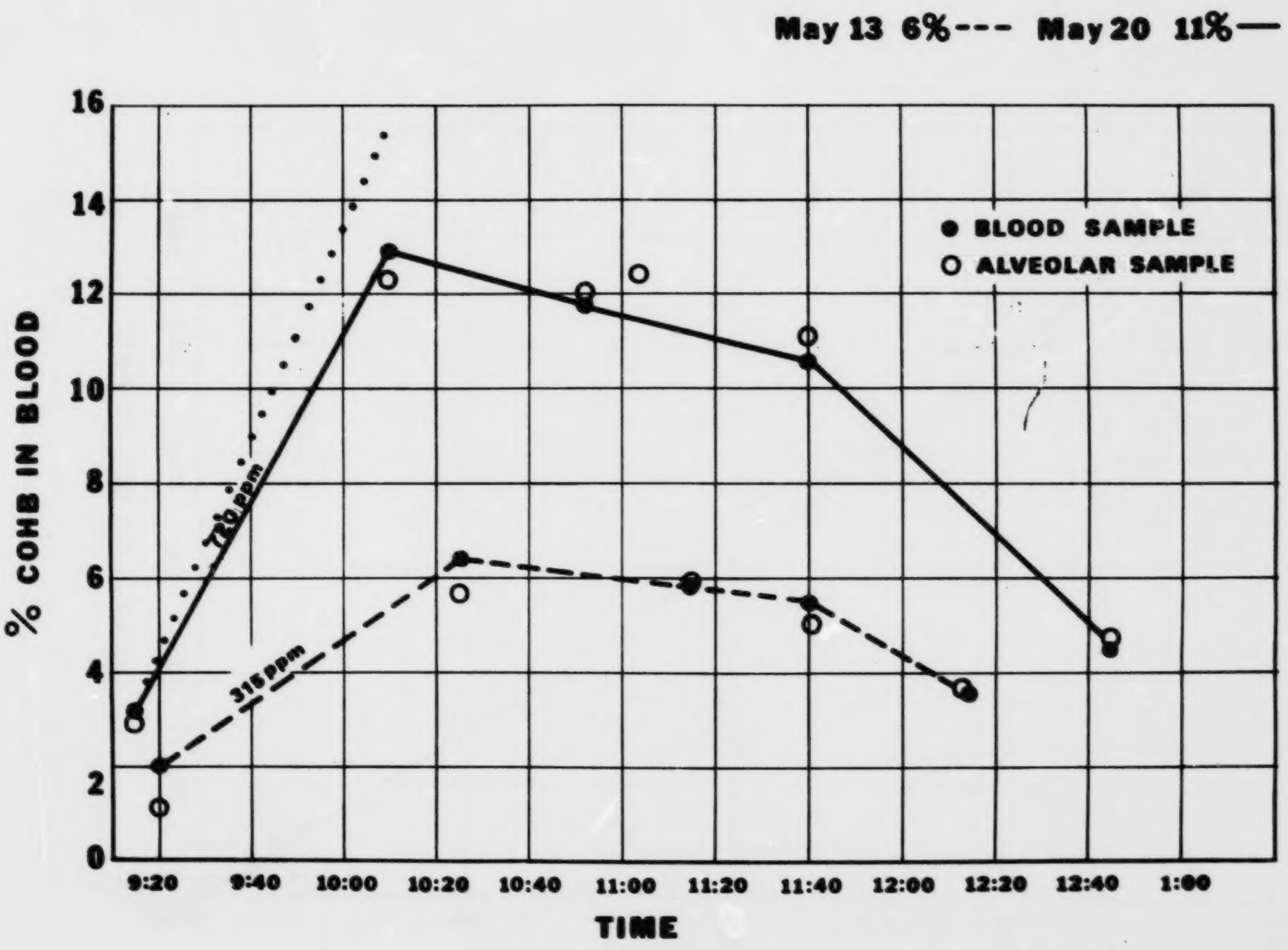


Figure 10. Uptake and elimination of CO in one typical subject in present study.

saturation value is reached. With a concentration of 720 ppm in the inspired air the equilibrium value is 57% so that one would expect to be unable to measure any deviation from linearity until 19 or 20% COHb is reached.

A wide range in the rates of uptake in our 28 subjects was found, as is indicated in accompanying Figure 11. In these graphs both the 11% and 17% experiments are shown and the rates calculated from each. In both experiments they were exposed to the same 720 ppm of CO and the only difference was the time of exposure. In 8 of the 9 subjects the discrepancy between the two runs is well beyond the experimental error of the measurements and is almost certainly due to differences in subject activity (i.e., restlessness or dozing). There was no consistency as to which run was higher, that is, sometimes it was the 11% run (which was the first one in all but two subjects) and sometimes the 17% run. The values for each subject are shown in the Appendix D.

The age of the subjects is shown on the graphs as is their cigarette use. The black dots indicate cigarette smokers, all of whom inhaled, and the half black dots designate light smokers. One man of 23, WM, who did not smoke cigarettes was, however, a light pipe smoker (2 or 3 pipefuls per day). He did not inhale and so was classed with the non-smokers. If the subjects are divided into three groups, the 8 who took up CO most rapidly, the middle 9, and the slowest 9, only two cigarette smokers are found in the first group, and four in each of the other groups. (The pipe smoker was in the first 8.) No conclusion should be drawn from these observations.

Our subjects ranged in age from 20 to 50, but only 5 were over 30. Their ages were 31, 33, 38, 41, 50. The 41-year old subject was also a cigarette smoker and was in the fastest group in CO uptake; the other 4 were in the slowest group. This is suggestive, but certainly not conclusive, evidence that age may tend to lower the rate of uptake of CO. It may be that the older subjects were less restless.

The great variability between subjects resulted in missing the desired percentage of COHb by an average of 16% of its value in the first experiment on a subject. The misses were equally divided between high and low. In our second experiment on the same man, the average miss was 7% also equally divided between high and low. The worst misses on the first experiments were +28% and -25%, and the worst on the second experiment were +14% and -14%. There was no demonstrable improvement in our ability to hit the target percent saturation in the first experiment on a subject as a result of experience with other subjects.

The elimination of CO in air was observed for slightly more than an hour in our first subjects. This was done by blood and alveolar samples just before and just after the series of tests. During this time the loss of COHb was about 17% of its value. In the later work an effort was made to keep the COHb more constant during the tests by giving a "refresher" dose of CO half way through the testing period, that is, 30 to 35 minutes after the start of the tests. This

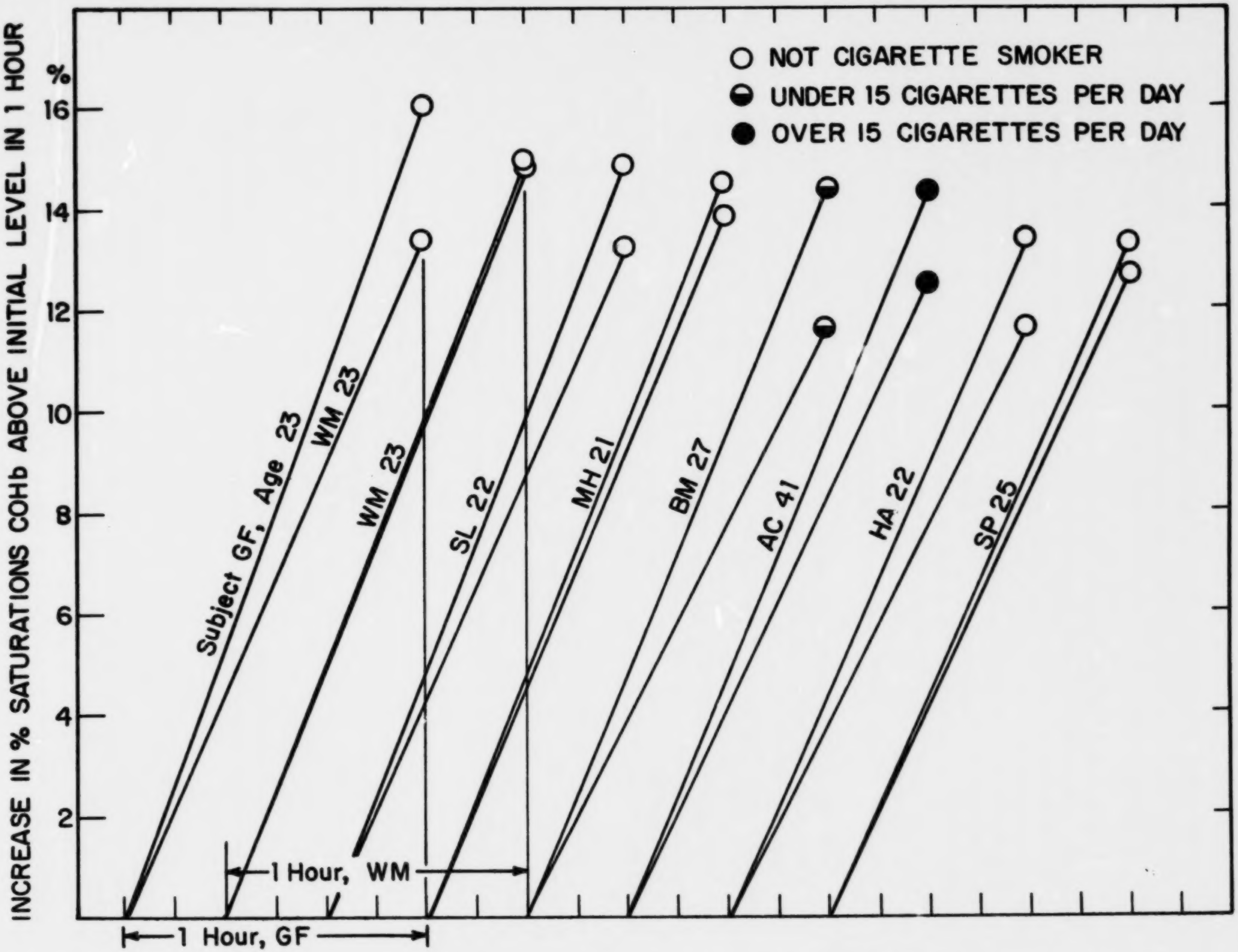


Figure 11. Rates of uptake of CO at 710 ppm: 2 determinations (23 subjects), 1 determination (3 subjects).

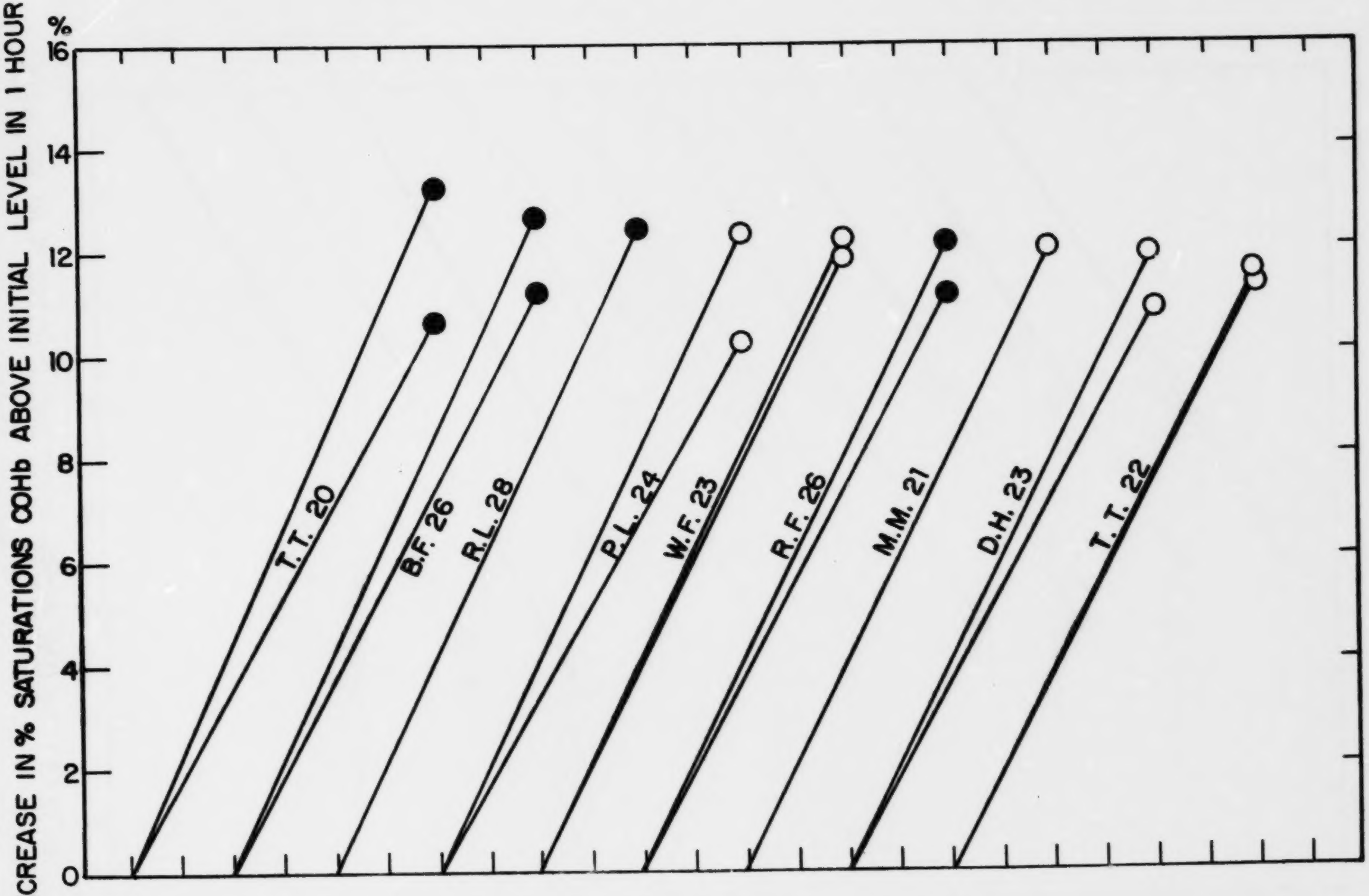


Figure 11 (continued)

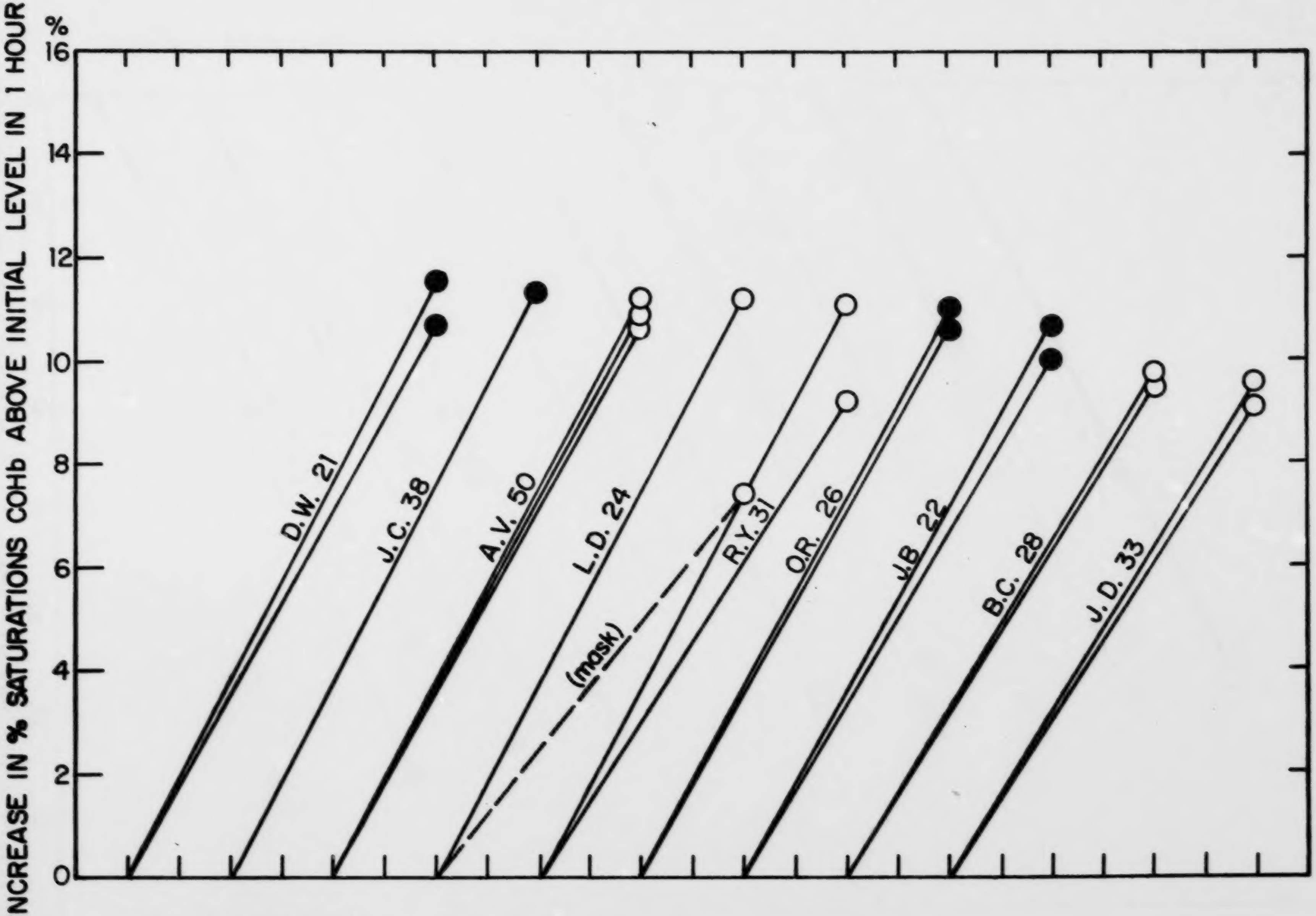


Figure 11 (continued)

meant that the fall in COHb was between 1 and 2 percent COHb - too small a change to be measured accurately, and consequently the figures from the earlier work which are presumably about twice as accurate are given here in Figure 12.

The rate of elimination of CO when breathing room air may vary in different subjects from about 11% to 19% per hour with an average value of 15%, the figure generally found in the literature for men in sedentary occupations (elimination increases with the respiratory ventilation). Figure 12 shows the rate of elimination of CO of subjects in the present study when breathing room air. Breathing 99% O_2 increases the rate of elimination by a factor of 3.5 to 4, again with a considerable variation among subjects. On the average, 55 or 60% of the CO is eliminated in the first hour, and 60% of the remainder is eliminated in the next hour. (See Figure 13.)

In contrast to the uptake of CO, which is linear or virtually so, the elimination of CO is logarithmic, and also, in air, is slower than the uptake, being about 15% of whatever the current value is per hour. However, under the conditions of our experiments in which we wished to avoid keeping the subjects at high levels (17% COHb) for any longer than necessary, small errors in measurement could make considerable errors in our estimation of the rate of elimination. Since our subjects were put on O_2 as soon as the tests were finished, we usually had only about an hour, often less, to observe the rate of fall of COHb from, say 18% to 15.3%. Thus, an error of 0.3% in either figure would make over 10% error in our estimation of the rate of elimination. This prevented any accurate determination of the rates of elimination in these cases.

The rates of elimination in oxygen, however, could be, and were, measured with much greater accuracy. Again there were considerable differences between the various subjects. There were also complicating factors such as the degree of activity of the subjects and the fit of the masks through which the O_2 was delivered. The elimination of CO was usually between 3 and 4 times as fast in O_2 as it had been in air. It was not as great as might be expected from the fact that the O_2 pressure theoretically was 6 times as great. In practice, however, the dead space of the mask plus the possibility of leakage of air into it lowered the rate of elimination. Approximately half (sometimes a little more) of the COHb in the blood was eliminated each hour while breathing oxygen at rest.

The numerical values for the rate of elimination of CO for each subject while breathing air and also while breathing oxygen, are shown in the Appendix E. As these observations were not a primary objective of this study, but purely incidental to it, the design of the experiments was not optimal for obtaining great accuracy in these measurements. However, the average values probably give a reasonably accurate picture of the rates of elimination of COHb in air and in a mixture of 99% oxygen and 1% carbon dioxide. The considerable amount of individual variability or scatter of the results is due in part to (1) individual differences and (2) the measurements being made over a short period of time. The protocol of the experiment required that each subject could not be released until the COHb level had reached 6% or lower. It was for this reason that the values on rate of elimination of CO were obtained.

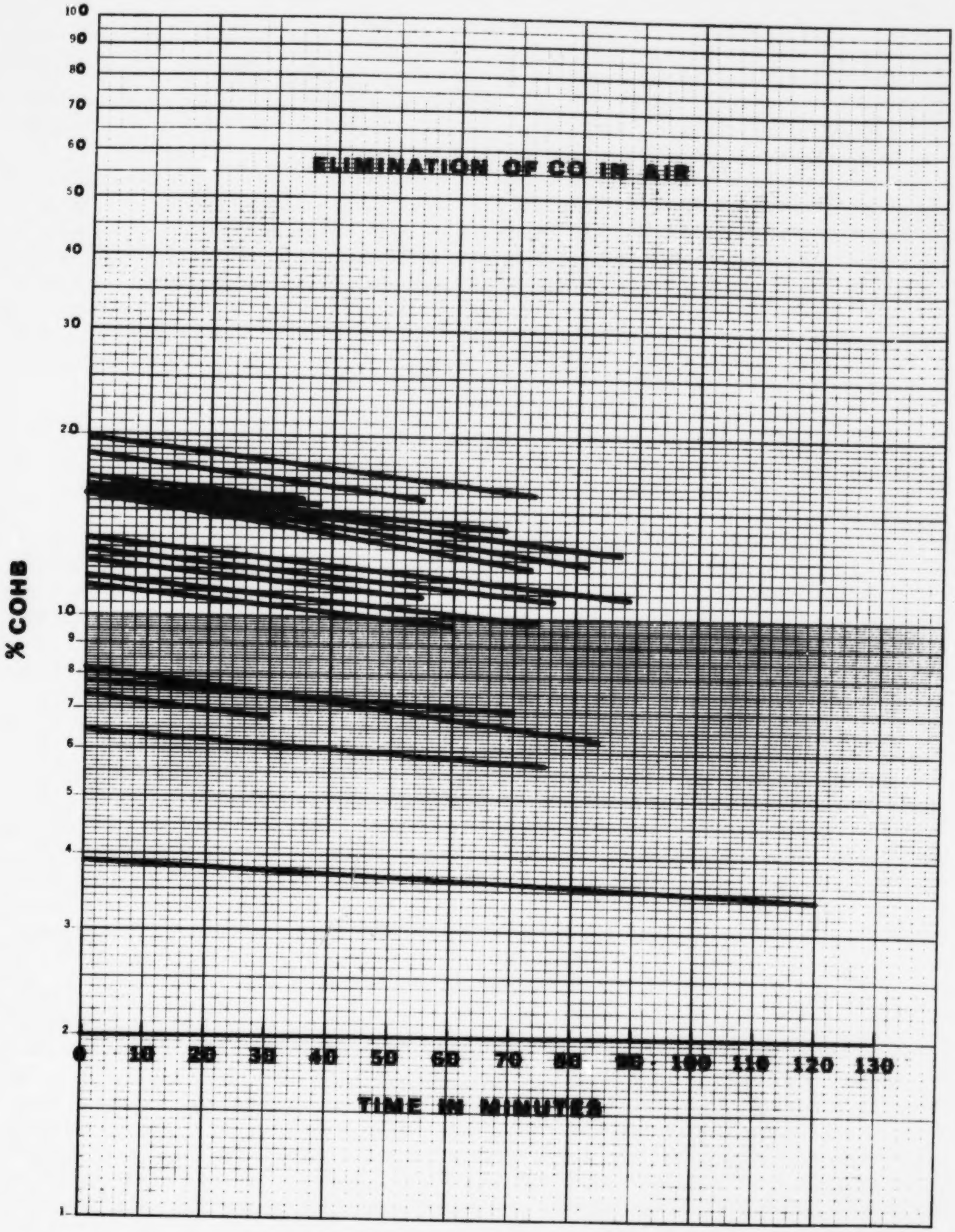


Figure 12. Elimination of CO of subjects in present study when breathing room air.

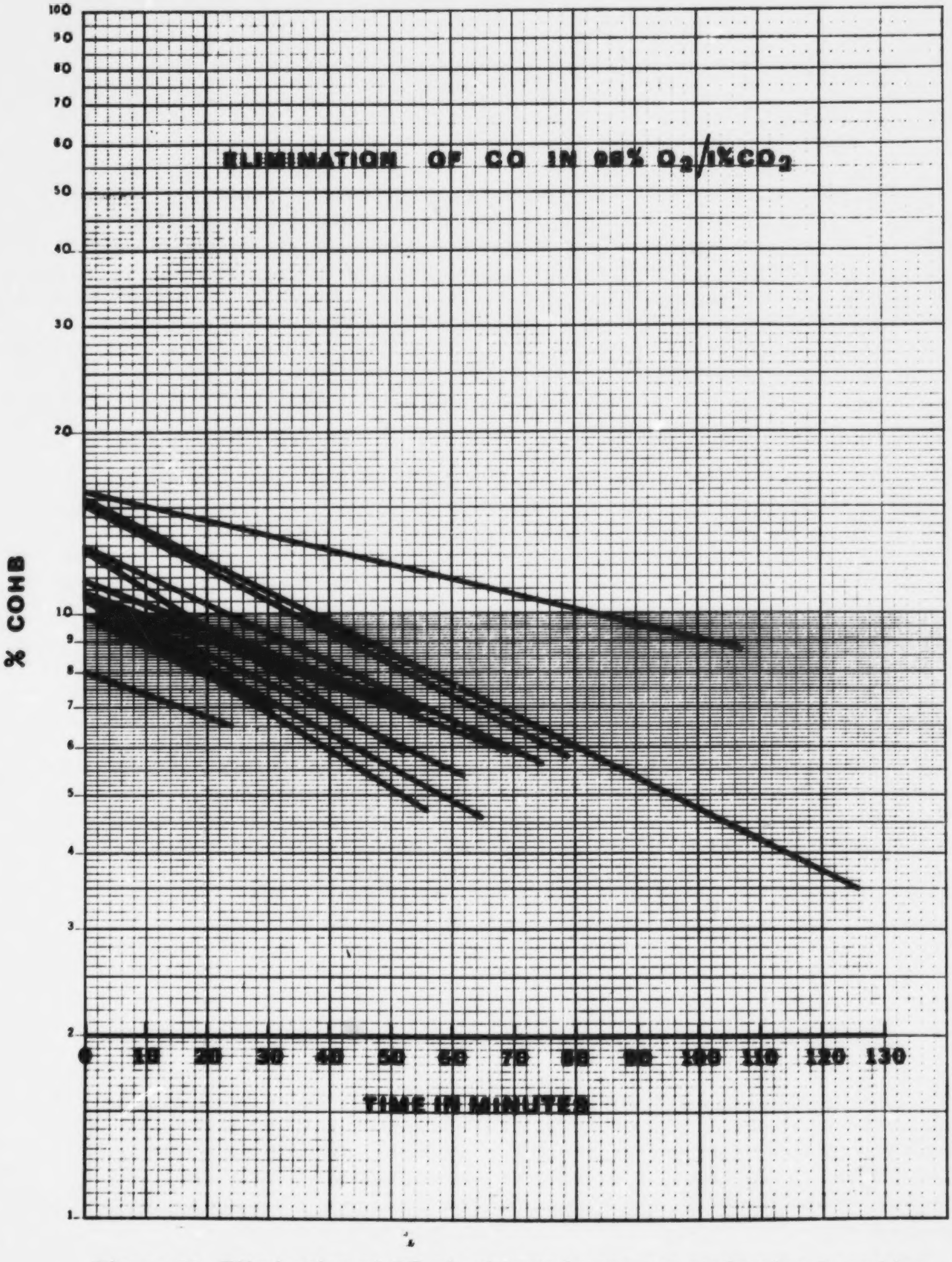


Figure 13. Elimination of CO of subjects in present study when breathing 99% O_2 - 1% CO_2 mixture.

IV. Laboratory Tests of the Effects of Carbon Monoxide

A. Introduction

The laboratory tests used in this study were designed to detect the effects of relatively small amounts of carbon monoxide on human performance on tasks related to vehicle driving. More specifically we wished to utilize objective methods for appraising the effects of carbon monoxide on the oxidative mechanisms of the central nervous system. The alteration of certain visual functions by hypoxia andother physiological stresses has yielded results of considerable theoretical interest and practical significance. The study of vision under such conditions is important because visual functions are believed to reflect changes in the central nervous system, of which the retina of the eye is essentially a part. In addition, vision is one of the primary functions or requirements of the driving task.

The accuracy of such studies has, in the past, often been limited by the nature of the specific test or physiological function used as an index of impairment. To obtain satisfactory results a test should possess certain features including: (a) a high degree of sensitivity; (b) precision of the physical measurements involved; (c) independence of the results from the degree of conscious or unconscious effort which may be exerted; and (d) stability of the function during control experiments.

Tests of certain visual functions, particularly light sensitivity, possess most of these desirable qualities. They provide a useful took with which to measure the effects of hypoxia and related stimuli. The changes manifested by the visual mechanism when its oxidative processes are disturbed are of considerable magnitude. The physical measurements of light intensity involved in these tests can be made very accurately. Moreover, the control of such experiments is simplified by the fact that the subject is not aware of changes in his own visual sensitivity or changes in the physical intensity of the stimulus, since, at the threshold level, the stimulus always has the same appearance. The subject, therefore, cannot mask the impairment by exerting additional effort. The specific tests used in this study, which contained most of the above features, were: (1) central-peripheral complex reaction task; (2) dark adaptation and glare recovery; (3) peripheral target recognition, and (4) depth perception.

B. General Procedures

In our initial experimental design, laboratory testing was carried out under four different levels of exposure: 0% COHb (in practice 4% or less), 6%, 11% and 17%. Each subject was exposed to one of these levels on each of four different days. In all cases, however, the general procedures followed were similar. At no time during the course of the laboratory tests did any subject know to which of the four levels of carbon monoxide he had been exposed.

All subjects were paid $20 per session. In the first phases of the laboratory work, subjects were tested first under the control condition, followed by a randomized sequence of the three COHb levels. Later the levels were randomized. In addition, for each subject the same fixed order of presentation of laboratory tests was followed for all of his four sessions.

The overall experimental procedure on each day, regardless of which of the four gas mixtures was used, was as follows: As soon as the subject arrived at the laboratory, usually about 9:00 a.m., blood and alveolar samples were taken to determine COHb levels at that time. Immediately following he was given pretests on the glare recovery-discriminometer test, and the central and peripheral complex task (see below). When this was completed, usually in about 45 minutes time, the subject was placed on his gas mixture for 80 minutes, at the conclusion of which both blood and alveolar samples were taken to determine his COHb level at the beginning of the testing period. After about 35 minutes, when half of the tests were completed, the subject was again exposed to his gas mixture for that day to restore his COHb to the intended level. Alveolar samples were taken immediately before and after this "refresher." The remainder of the tests were then carried out, whereupon both blood and alveolar samples were again taken. The subject was then "washed out" with the O_2-CO_2 mixture for about 60 to 90 minutes, depending on his COHb level, whereupon his final blood and alveolar samples were taken. He was then released for the day.

C. Complex Central-Peripheral Reaction Test

1. Test Procedures

A method devised during recent years to measure the effects on human performance of moderate stresses or small amounts of various noxious agents has involved the simultaneous performance of two separate tasks. It has been shown in various experiments that under such circumstances performance on a main task often may show no measurable decrement. However, the ability to carry out a subsidiary concurrent task may be impaired, as measured by various objective criteria, with the effect of the agent under study interpreted as reduced "reserve capacity."

The Complex Central-Peripheral Reaction Test used in the present experiment was adapted from procedures previously developed in the Guggenheim Center at Harvard for measuring effects of environmental variables on performance, especially in studies relating to altitude. The test task shares with driving the need to make accurate and rapid responses to visual events occurring simultaneously or sequentially in different parts of the field of view.

The primary task was to respond to red or green lights displayed in the central field of vision by pressing foot switches, right for green and left for red. These stimuli, 440 in all, were presented in random order at regular 2-second intervals throughout the 15-minute test. The stimulus lights were extinguished by a subject's making a response, or in the case of no response, they automatically went off at 1.7 seconds.

The stimuli for the secondary task were small white lights appearing in random order at any of six locations in the peripheral field. These were at 15°, 30°, or 45° from center, both right and left. The subject responded to a peripheral light by pressing the appropriate finger button from 3 on the left and 3 on the right which corresponded to the location of the light. There were 96 peripheral stimuli in each test, 16 at each location, separated by intervals ranging from 4 to 11 seconds. Each stimulus had a duration of .6 second. Time of presentation was randomized across the 20 one-tenth second points within the two-second interval between central stimuli.

The display-response apparatus with a subject in position is shown in Figure 14. A Varatek PDP-8/S Computer programmed for randomized stimulus presentation and linked with a teletype console for instructions and automatic recording was located in an adjacent room. This arrangement provided a continuous time-based record (to .01 second) on punched paper tape of all stimulus and response events throughout the 15-minute test. These data were then transferred to magnetic tape for computer processing.

Test performance on the complex reaction test was measured on different days under three conditions: (1) a "control" session, after subjects went through the "gassing" procedure, but were exposed only to room air; (2) when CO was administered and a COHb level of 11% was attained, and (3) similarly, at 17% COHb. Subjects were given a period of practice on the apparatus on a day previous to any testing, and on test days a 5-minute warm-up "run" on the apparatus immediately preceded the experimental test.

Order of test sessions was randomized with respect to the control and 11% COHb days. Scheduling problems and some equipment malfunctions, however, resulted in the majority of subjects performing the 17% COHb test at the last of the three sessions.

Valid records for analysis were obtained on twenty-three subjects, with twenty under all three conditions. For two subjects data were available only for control and 17% COHb tests; one subject performed only under control and 11% COHb.

2. Results

The basic information in the individual test records included whether or not a particular central or peripheral stimulus was followed by a response, whether a response was correct or incorrect, and when each response was made. In addition, the continuous real-time recording of all events in a test provided the basis for an analysis of interactions between central and peripheral stimuli and responses in relation to the sequences of events and their time relationships.

The results are presented in terms of the effects of CO on overall measures of performance on both central and peripheral tasks, and in relation to interaction effects observed in the data. Specifically, the control-test comparisons were

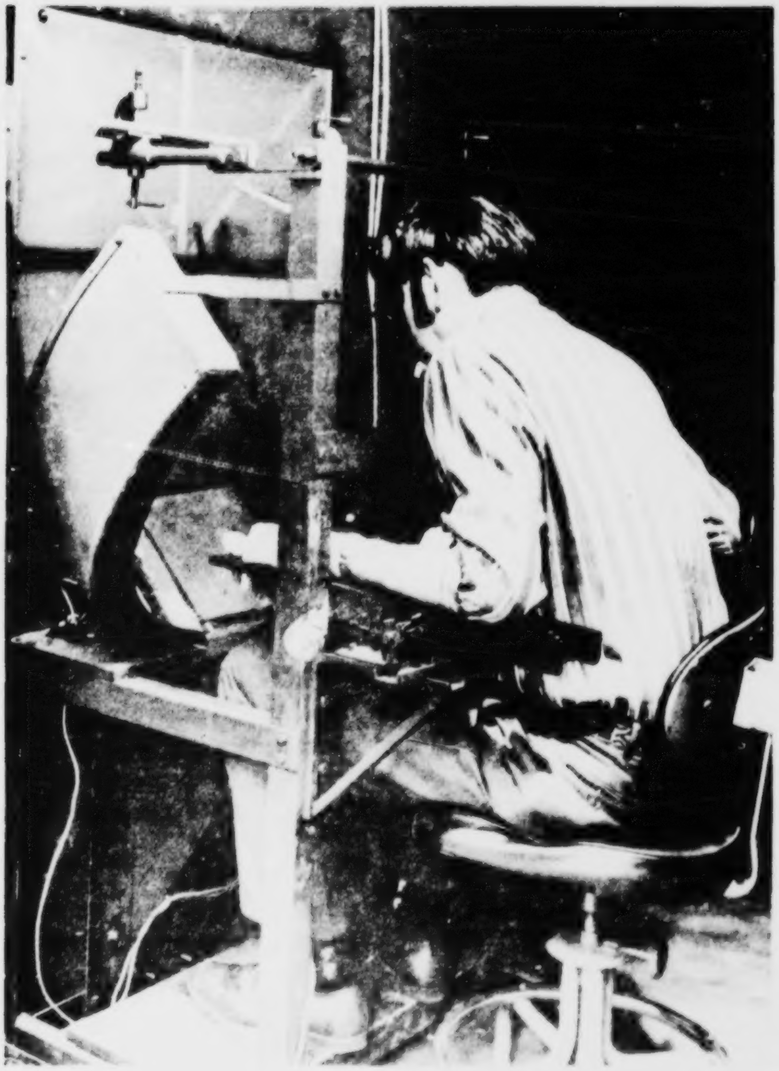


Figure 14. Central and peripheral complex task. Subject reacts with foot switches to red or green lights displayed in the central panel. Simultaneously he responds with the appropriate finger-activated buttons as the six lights on the perimeter are illuminated.

made in regard to the total numbers of correct, incorrect, and omitted responses, response times, incorrect and omitted responses in relation to peripheral stimulus location, frequency of "response blocking," and the influence of stimulus proximity on peripheral responses and response times.

a. Effects of CO on Overall Performance - Central Task

1. Numbers of Correct, Incorrect, and Omitted Responses

The summary data relating to correct, incorrect, and omitted responses in the central task are shown in Table 1 for the control vs. 11% COHb and control vs. 17% COHb tests separately. The differences in Table 1 between the mean values under control and CO conditions are obviously small, subject variability was considerable, and the pattern of changes in the distribution of means among the three categories of response is not consistent across the two groupings. While mean changes between control and 11% COHb appeared to be in the direction of "poorer" performance under CO, none were of sufficient magnitude to reach the .05 level of significance (paired difference "t" tests). Even in the case of correct responses, where the numbers per subject were relatively large, the probability corresponding to the "t" was between .08 and .09.

Comparison of the means for control and 17% COHb does not suggest any real change. The pattern of very slight numerical differences observed would seem to be a reversal of that in the other set of data, but none of the "t" tests of the differences were significant, or were even borderline in that respect.

Since the subjects were generally more familiar with the test at the time of performance under 17% COHb, the above results raised the possibility of a confounding of possible effects of CO and test familiarity or practice. Thus, the control vs. 11% COHb data were divided according to whether the CO test was taken on a day subsequent to the control test (experienced group) or on a day prior to the control test (inexperienced group). A comparable division could not be made of the 17% data.

The mean changes in numbers of correct, incorrect and omitted responses in control vs. 11% COHb tests (i.e., COHb minus control) are given in Table 2.

Table 1

Central Responses - Control vs. 11% COHb Tests (21 Subjects)

Test	Number of Correct Responses			Number of Incorrect Responses			Number of Omitted Responses		
	Range	Mean	S. D.	Range	Mean	S. D.	Range	Mean	S. D.
Control	348-435	413.3	17.48	1-31	12.95	7.72	0-56	10.62	12.41
11% COHb	343-434	407.4	21.29	3-57	14.76	11.47	0-42	14.19	13.57

Central Responses - Control vs. 17% COHb Tests (22 Subjects)

Control	348-435	413.8	17.25	1-31	13.23	8.46	0-56	10.09	12.39
17% COHb	563-430	415.9	18.56	0-55	12.50	12.24	0-46	9.32	10.33

Table 2

Change in Average Numbers of Central Responses in Subjects Grouped by Order of Test Days*

Central Responses	Experienced Group (N-10)	Inexperienced Group (N=11)
Correct	-1.18	-11.1
Incorrect	- .27	+ 3.9
Omitted	+1.64	+ 5.4

* +indicates increase in CO test over control; - indicates decrease in CO test from control.

None of the differences between means in the "Experienced" column were statistically significant. In regard to those in the "Inexperienced Group", the decrease in correct responses and the increase in incorrect responses under CO were significant at $P < .057$, $> .02$. The mean increase in omitted responses did not reach significance (P approximately .15). Additional "t" tests were also carried out for the row values across the columns. The difference for "correct" responses approached significance ($P = .08$); those for "incorrect" and "omitted" were well within chance expectations.

The data were also analyzed for effect of day, with control and 11% COHb data treated separately. The average numbers of correct, incorrect, and omitted responses obtained are shown in Table 3.

Table 3

Average Numbers of Central Responses by Day of Test

A. Responses	Control Test on First Day (N-11)	Control Test on Second Day (N=10)	Differences Between Means (Day 2 -Day 1)
Correct	410.4	416.5	+6.1
Incorrect	16.5	9.1	-7.4
Omitted	9.7	11.6	+1.9

B.	11% Test on First Day (N=10)	11% Test on Second Day (N=11)	
Correct	405.4	409.3	+4.1
Incorrect	13.2	16.2	+3.0
Omitted	17.3	11.4	-5.9

There is a suggestion of "better" performance with practice in the increase in mean numbers of "correct" responses in day 2 tests over day 1, and also in the corresponding decrease in the totals of incorrect and omitted responses. However, the only change reaching statistical significance is the smaller number of incorrect responses in the control test performance of those taking the test on the second day, as compared to those having control first.

It thus appears there are some factors of test experience or order of test day operating in the data which might obscure possible effects of CO. However, significant impairment from CO, in terms of decreased numbers of correct central responses, and an increase in incorrect responses can be demonstrated only in the case of minimal prior experience in the test. Thus, the foregoing analysis suggests that a deleterious effect from COHb in this amount may be most apparent during the learning period of a task, with the implications for driving relating to performance in unfamiliar or novel situations.

2. Reaction Times, Central Task

The average reaction times per subject to central stimuli ranged from

.38 sec. to .85 sec. in the control tests, .39 to 1.14 under 11% COHb, and .38 to .87 with 17% COHb. The means of the individual averages are shown in the table below, with times for correct and incorrect responses shown separately. Both simple means and means adjusted to take account of differences in the numbers of response times available per individual are given, along with the adjusted means for correct and incorrect responses combined.

Table 4

Summary of Response Times to Central Stimuli

	Simple Means of Average Response Times*		Adjusted Means of Average Response Times		
Test Condition	Correct Responses	Incorrect Responses	Correct Responses	Incorrect Responses	Combined Correct and Incorrect Responses
A.					
Control	.661	.633	.661	.605	.660
11% COHb (N=21)	.668	.640	.666	.650	.660
B.					
Control	.673	.547	.673	.615	.672
17% COHb (N=22)	.666	.588	.665	.653	.664

*In seconds.

In general, individuals tended to be quite consistent in the different test conditions, i.e., relatively slow or fast in all. When the mean times for individuals varied between control and CO conditions, small increases or decreases appeared equally often and seldom exceeded a few hundredths of a second. It is interesting to observe the slightly shorter response times for incorrect compared to correct responses in the Table. However, a differential effect related to CO in this regard could not be demonstrated. The summary data thus do not indicate any demonstrable effect of CO at these levels on reaction times in the central task.

b. Effects of CO on Overall Performance - Secondary Task

1. Numbers of Correct, Incorrect, and Omitted Responses

The average total numbers of correct, incorrect, and omitted responses are given in Table 5. It should be noted that omitted responses to stimuli at one of the peripheral locations (15° to the right) have been deleted from the totals, since an equipment malfunction had resulted in a spurious count of omitted responses to this light.

Table 5

Summary - Numbers of Peripheral Responses

	Correct Responses		Incorrect Responses		Omitted Responses	
Condition	Mean Number	Standard Deviation	Mean Number	Standard Deviation	Mean Number	Standard Deviation
A.						
Control	73.3	12.89	8.9	7.02	9.2	8.00
11% COHb (N=21)	72.9	16.62	10.2	9.80	10.7	12.0.4
B.						
Control	72.4	13.53	6.7	6.72	11.1	9.58
17% COHb (N=22)	72.9	13.74	6.7	6.66	13.1	10.29

The differences between the mean values above are obviously small. Numerically, a small increase appears in both average numbers of incorrect and omitted peripheral responses in the 11% COHb tests, and in omitted responses in the 17% tests. However, individual variability was great and none of the differences proved to be significant with these numbers of subjects. There is also a suggestion of greater variability under CO in the data for control vs. 11% COHb. Here the F ratio of the variables was significant at the .05 level in the case of the omitted responses.

An analysis in reference to experience with the test was also performed on these data. The changes between mean numbers of the peripheral responses between control and 11% COHb tests for the "experienced" and "inexperienced" subjects (as previously defined) are given below.

Table 6

Changes in Average Numbers of Peripheral Responses in Subjects Grouped by Order of Test Days

Peripheral Responses	Experienced Group (N=10)	Inexperienced Group (N=11)
Correct	-1.09	+ .50
Incorrect	-2.82	+4.90
Omitted	+3.18	-2.40

None of the mean changes between control and CO values are significant in either the "experienced" or "inexperienced" group. When the comparison is made across rows, the reversal in the case of incorrect responses reaches borderline significance (P = .06), again suggesting relatively greater inaccuracy under CO if the task is being learned.

2. Numbers of Incorrect and Omitted Responses in Relation to Location of Stimuli in the Peripheral Field of View

Previous studies have suggested that stimuli in the periphery of vision, as compared to central location, are more likely to be "missed" after exposure to CO. In the present data, this question involved a comparison between control tests and those under CO in regard to the frequency of incorrect and omitted responses to peripheral stimuli at each of the six locations, i.e., 15°, 30°, and 45° from center, to both right and left. The average numbers of incorrect peripheral responses, by stimulus location, are shown in Table 7, and the corresponding data for omitted responses in Table 8.

A consistent pattern suggesting an effect from CO is not apparent in regard to the incorrect responses. Numerically, there were larger numbers of incorrect responses under both CO levels at the 45° left position, but the difference was not statistically significant in either case. The suggestion of slight increases under 11% COHb at the two 15° positions is reversed in the 17% COHb data. Overall, five of the means were numerically larger under CO, as against seven which decreased under CO. The difference between means was significant ($P < .05$) only in one case, i.e., there were significantly fewer incorrect responses at 30° left under 17% COHb as compared to control.

Table 7

Average Number of Incorrect Peripheral Responses by Stimulus Location

	Left		Center		Right	
	45°	30°	15°	15°	30°	45°
Control	1.24	2.33	1.62	.67	1.76	1.61
11% COHb (N=21)	1.48	2.05	1.95	.71	1.00	1.76
Control	1.09	2.50	1.45	0.59	1.64	1.40
17% COHb (N=22)	1.27	1.18	.77	0.18	1.91	1.36

Table 8

Average Number of Omitted Peripheral Responses by Stimulus Location

	Left		Center		Right	
	45°	30°	15°	*15°	30°	45°
Control	2.28	1.28	1.71		1.52	2.24
11% COHb (N=21)	2.05	1.62	2.09		2.43	2.24
Control	2.68	1.59	2.04		1.95	2.77
17% COHb (N=22)	3.32	1.59	2.23		3.14	2.27

*As previously noted, "omitted response" data at this location were found to be invalid.

In regard to Table 8, small numerical increases in mean numbers of omitted responses under CO appear in three of the five comparisons at the 11% level and four of the five at 17%. However, in only two of the ten did any of the differences reach statistical significance. At 30° right the increases in mean number of omitted responses over control at both levels of CO were significant at $P < .05$.

Obviously, the foregoing does not provide adequate answers concerning the influence of stimulus peripherality on response, or a differential effect of CO in this regard. One problem was that with only 16 stimuli at each location per test the numbers of incorrect and omitted responses per location per subject were very small. Also, variability in the data was found to be affected by two other factors. In general, relative propinquity in time of peripheral and central stimuli had an influence on the frequency of omitted responses. In addition, frequencies of stimuli at the different presentation times did not turn out to be sufficiently uniform for making precise comparisons.

3. Effect of CO on Frequency of Instances of Response Blocking

The phenomenon of "response blocking" was first recognized and studied systematically by Bills (1937) who noted that subjects performing long series of repetitive operations tended to show occasional gaps in performance during which the desired responses were not made even though the stimuli were present. Generally, such gaps have been interpreted as reflecting attentional lapses in high speed, continuous, decision-making tasks. In more recent years "blocking" has been considered in the framework of the human as a communications system, along with other human time lags, but still with an emphasis on an attentional mechanism. (Broadbent, 1958; Teichner, 1968) In general, "blocks" have been found to occur periodically throughout a response series, and may include from 2-6 consecutive responses. They tend to increase in frequency and duration with increasing complexity of the task and/or rate of information flow. Prolonged time at the task, sleep loss, and environmental stresses, such as anoxia, have also been shown to increase blocking. Driving is a type of task similar to many of those in which "blocking" occurs, and certainly is one in which failure to respond to external cues could under some situations prove very hazardous.

In the present experiment, an "instance" of response blocking was defined as failure to respond to a peripheral stimulus in conjunction with failure also to respond to the central stimulus next preceding and/or next following the peri-stimulus. A few individuals showed one or more instances of such response blocking under both control and experimental conditions: about half did not show any instances under any of the conditions. Table 9 below presents an analysis of the numbers of subjects in whose records instances of response blocking were found under the different test conditions, together with the corresponding X^2 and P values.

Table 9

Comparison of Numbers of Subjects with One or More Instances of Response Blocking in Control and CO Tests

Test Condition	Number of Subjects With One or More Response Blocks	X^2, P
Control	5	3.634, P = .07
11% COHb (N=21)	11	
Control	4	3.804, P = .052
17% COHb (N=22)	11	

Slightly more than twice as many subjects showed one or more instances of blocking in the tests under CO as in the control tests. With the small numbers of subjects involved, the significance of the X^2's is only borderline. The P value in the second comparison is just about at the .05 level, while that in the first is at .07. Thus, while there is a strong suggestion that some persons may be more susceptible than others to response blocking after exposure to CO at these levels, the present finding requires further verification.

Analysis of the data in regard to numbers of response blocks was made on the basis of the total numbers of "blocks" for all subjects under a given test condition in relation to the total numbers of omitted responses. The results were in the direction of an increase in the numbers of instances of response blocking in the total group under both CO levels as compared to control. However, in neither case did the X^2 value quite reach a statistically significant magnitude, with P approximately .09 and .07 for the 11% and 17% comparisons respectively.

The "response blocks" included some which involved failure to respond to a peripheral stimulus and to both the preceding and following central stimuli, i.e., "blocks" of considerable duration, lasting somewhat longer than 2 seconds. The numbers of subjects showing instances of this more protracted blocking were too few for adequate statistical testing; however, 2 of 21 subjects showed such blocks under control, vs. 5 at 11% COHb, and 3 of 22 under control vs. 10 at 17% COHb.

The test also at times involved relatively long sequences of central stimuli without an intervening peripheral stimulus. Hence, the data were also scanned for instances of failure to respond to two or more consecutive central stimuli in such series. The number of subjects showing this type of "block" was very small, and in view of the large numbers of central stimuli per test, these blocks were quite rare. One or more were found in the records of 4 of 21 subjects under control vs. 8 under 11% COHb, and for 3 of 22 under control vs. 7 at 17% COHb. A phenomenon which did not appear in any of the control records, but was found for two subjects in both 11% and 17% tests, for 1 at 11%, and 1 at 17%, involved complete failure to respond for periods exceeding 4 seconds. One subject failed to respond to 28 consecutive stimuli at one point in his 11% test; another did not respond to a series of 18 during the 17% COHb test; another missed 9 in a row. These lapses extended from 16 to over 40 seconds, and it is possible that these subjects may actually have fallen asleep for brief periods. However, the only evidence that this may have been related to CO is the lack of such episodes in the control test data, and a definite relationship cannot be established on the basis of the present data.

Previous work has indicated that "blocks" are characteristically preceded by increased reaction times just prior to their appearance. It would thus be desirable in relation to the present data to examine the reaction times just preceding the occurrence of isolated omitted responses for additional evidence of response blocking, and for making comparison in regard to possible effects of CO.

c. Effects of CO in Regard to Interactions Between Central and Peripheral Task

1. Frequency of Omitted and Peripheral Responses as a Function of Stimulus Presentation Times

Originally, a classification system of response categories based on stimulus response sequences had been devised for the analysis of interaction effects. Inspection of the data in this form suggested that responses to peripheral stimuli tended to be omitted more frequently when presented at times close to the onset time of a central stimulus. However, when the attempt was made to analyze the data tabulated into categories, variability between subjects and between tests was great, and consistent trends related to CO could not be demonstrated. A considerable source of the variation was the differences in numbers of stimuli appearing at the 20 separate presentation times. In a given individual test, there was a range in stimulus frequencies of from 0 or 1 to 10 or 12 at the different times, and the patterns of stimulus frequencies varied between subjects, and for the same individual between tests.

For an alternative approach, distributions were prepared of the total numbers for all subjects of peripheral stimuli appearing at each of the presentation times separately for the three test conditions. Corresponding distributions of the total numbers of correct, incorrect, and omitted responses were also prepared and plotted as proportions of the total numbers of stimuli presented at

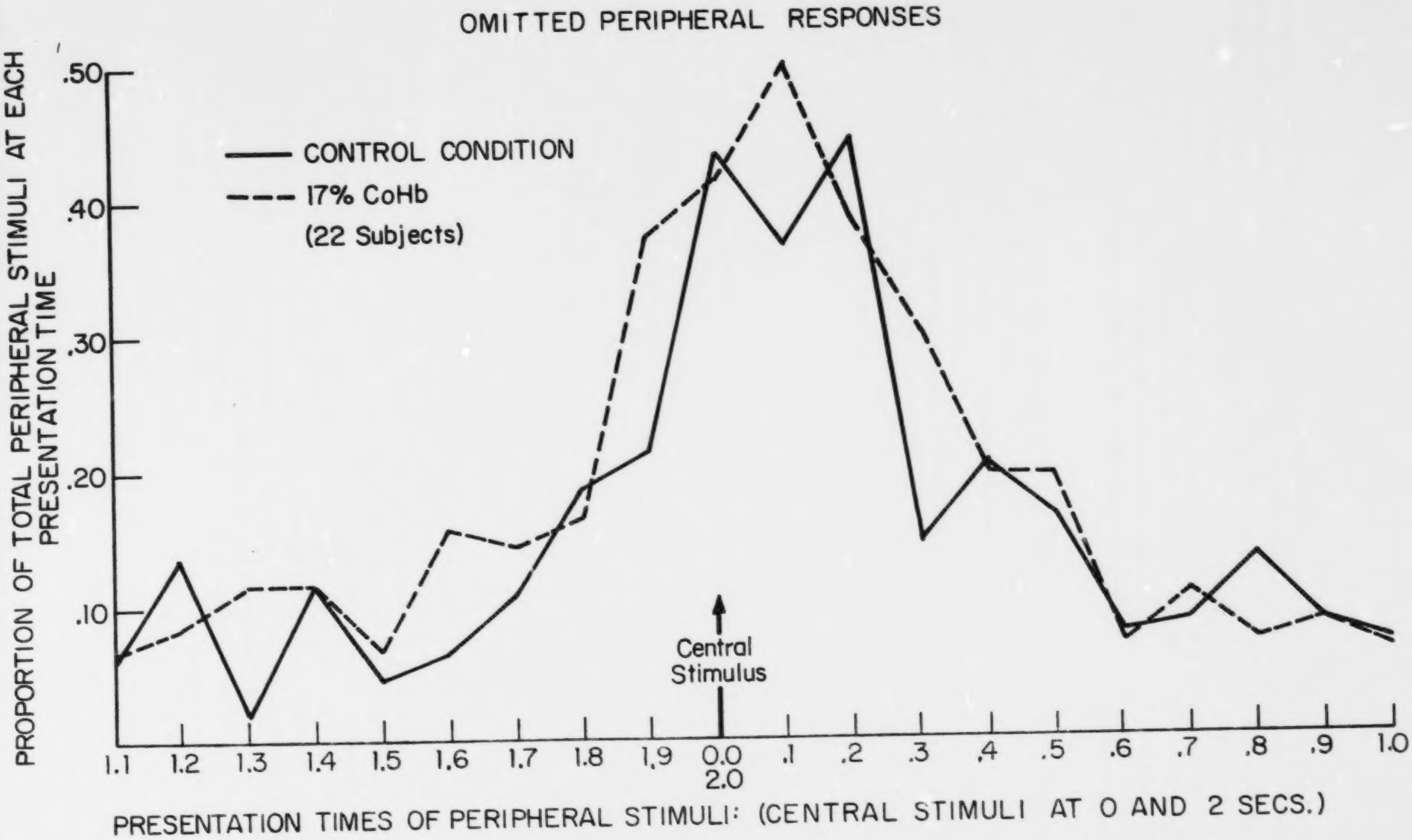


Figure 15. Frequency of omitted peripheral responses as a function of stimulus presentation time, relative to onset time of central stimuli.

each of the 20 time points. Inspection of these graphs suggested that incorrect responses tended to be fairly evenly or randomly distributed over the 20 presentation points under both control and CO conditions. Omitted responses, however, were relatively concentrated in a range of presentation times from shortly previous to shortly after a central stimulus. This pattern was characteristic for all three test conditions, with 30-50 percent of the stimuli at particular points close to central stimuli receiving no response. Figure 15 illustrates this relative concentration and shows the comparative distributions from control and 17% COHb tests.

Statistical comparison of the distributions was made through the calculation of Chi Squares for the interval .4 sec. prior to .5 sec. following central stimulus time, and in regard to the frequency data at the separate points in this interval. In the control-11% comparison none of the X^2 values reached the .05 level of significance. The distribution of the 17% data, however, was significantly different from control ($P < .046$, $> .025$) indicating a greater frequency of omitted responses in this area after CO than to be expected by chance. Also, the numbers of omitted responses at several of the individual time points were also significantly greater, notably at .1 sec. preceding, and .1 sec. and .3 sec. following the central stimulus point.

The suggestion here is that there may be a "normal" tendency for relatively increased likelihood of omitting a response to a secondary stimulus when it competes closely in time with a primary one, and this tendency may become enhanced after exposure to CO which eventuates in 17% COHb. Obviously the above suggestion requires confirmation, especially through procedures which would involve greater numbers of stimuli in the critical time areas and permitting more precise manipulation of effects of individual variability in the statistical treatment. The tentative finding does suggest an important direction for further research, not only in regard to effects of CO, but also for stimulus response relationships in the case of temporally and spatially competing stimuli.

2. Effect of CO on Peripheral Response Times

In the original computerized classification into ten stimulus-response sequence categories, the mean reaction times varied considerably within categories and between categories for individuals and test conditions. Observed changes between control and CO data were inconsistent in direction and magnitude. It became apparent that category frequencies and consequently numbers and variability of response times per individual per category were affected by variations in the numbers of peripheral stimuli at the different presentation times. In this regard the stimulus randomization program, in this number of subjects, did not result in the desired uniformity. Also, whether a given subject tended to be generally "fast" or "slow" influenced the relative allocation of responses between certain categories.

A further programming for computer analysis to provide comparisons of response times as based specifically on the stimuli appearing at each of the 20 successive presentation times would have been desirable but was beyond the financial resources of the project. It was, however, possible to make a rough approximation of the influence of central-peripheral interactions on peripheral response times and of possible effects of CO in this regard. Frequency distributions were prepared from the categorized data of all the response times for all subjects in respect to the stimuli at each presentation time and under the three test conditions. These were then plotted for each presentation time as proportions of the distribution of reaction times at that point falling into successive reaction time intervals of .10 seconds. Visual comparisons were made for changes across the 2-second span of presentation times and for differences between control and CO conditions. In instances where divergencies appeared, the statistical test for significance of differences in proportions was applied. In the inspection process, emphasis was placed on overall shape of the distributions, variations in central tendency, and relative frequency of prolonged response times.

Qualitatively, the plots ranged from a fairly uniform pattern quite characteristic from about .6 to 1.5, in terms of the presentation time points. Figure 16 illustrates the typical pattern for this range and also shows the comparative control and 11% COHb distributions at presentation time 1.1. In the range where peripheral and central stimuli were close together, or coincided, in time, the patterns were more irregular, more platykurtic, and with less clearly defined central tendencies. Figure 17 shows the plots at the point of simultaneous onset of stimuli for 21 subjects in the control and 11% COHb tests.

As a rough index of central tendency, the plots were inspected for location, and changes in location, of the modal intervals, i.e., the reaction-time interval containing the largest proportion of the response times. In the control data for 21 subjects the modal interval was the one including reaction times of .60-.69 sec., at 16 of the 20 presentation points, from .3-1.8 successively. At 1.9 time, the largest proportion was in .70-.79 sec. At 0.0 (stimulus simultaneity) the plots suggested possible bimodality in peaks at .60-.69 and .90-.99 sec. (See Figure 17) These observations suggest that when central and peripheral stimuli appear at the same time, or in close temporal proximity, peripheral response times may tend to be slightly longer, on the average, or more variable, compared to responses when the stimuli are more remote in time.

In general, only minor variations between the distributions under control and 11% COHb, and control and 17% COHb were observed, and the patterns in the plots were very similar. In regard to the 11% level, the location of modal intervals coincided closely with those in the control plots, and there was a clear difference in this regard at only one point. At time .1, the modal interval was .90-.99 sec. with CO, compared to .70-.79 sec. in control. The variability in both control and CO plots at 0.0 time prevents a clear comparison of the modal intervals.

The distributions of response times under control and 17% COHb followed the same patterns described above quite closely, except that, in the middle range of stimulus times, the 17% COHb modal interval in several instances shifted to

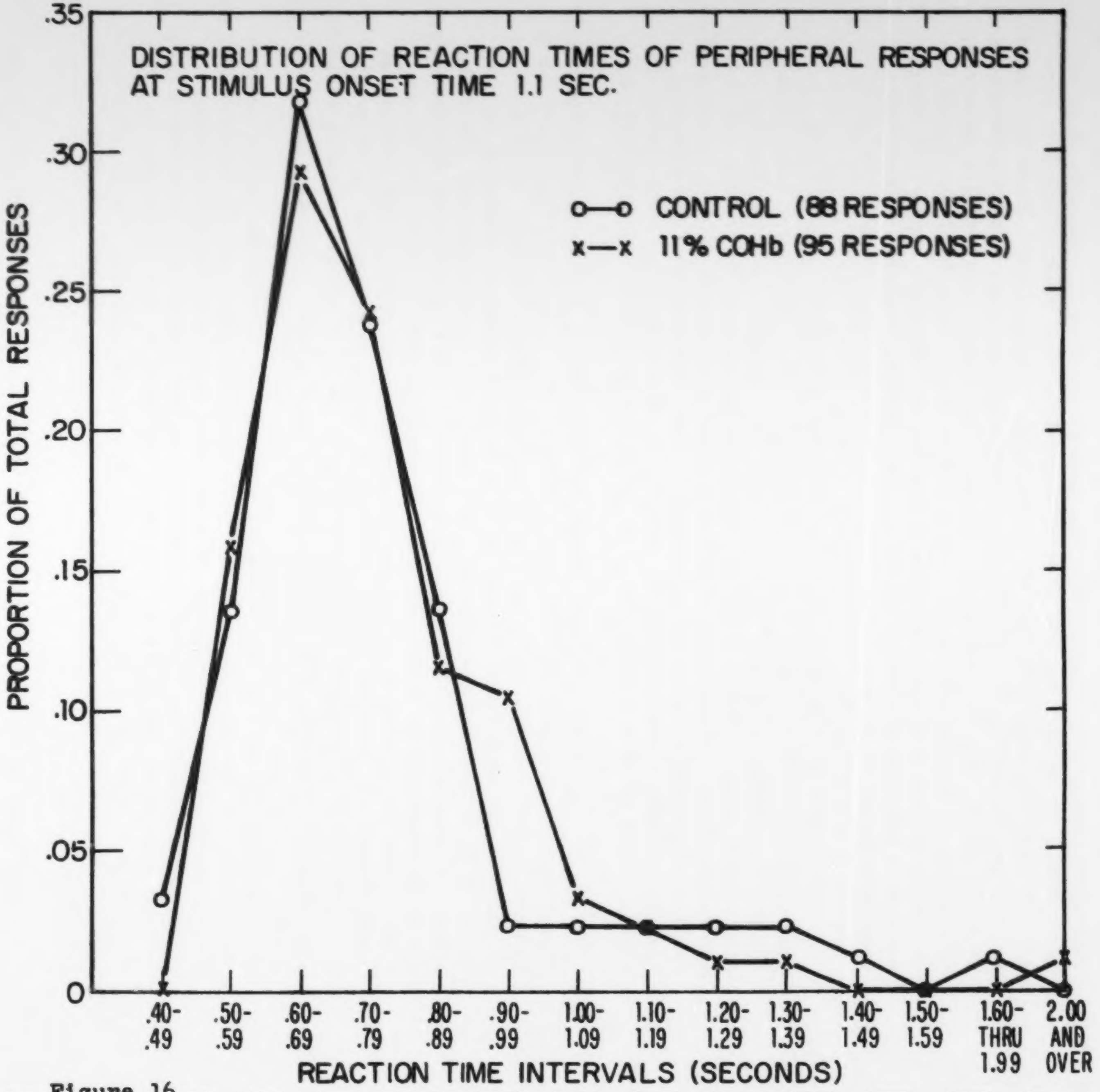

DISTRIBUTION OF REACTION TIMES OF PERIPHERAL RESPONSES
AT STIMULUS ONSET TIME 1.1 SEC.
CONTROL (88 RESPONSES)
11% COHb (95 RESPONSES)
PROPORTION OF TOTAL RESPONSES
.35
.30
.25
.20
.15
.10
.05
0
.40-.49
.50-.59
.60-.69
.70-.79
.80-.89
.90-.99
1.00-1.09
1.10-1.19
1.20-1.29
1.30-1.39
1.40-1.49
1.50-1.59
1.60-THRU 1.99
2.00 AND OVER
REACTION TIME INTERVALS (SECONDS)

Figure 16

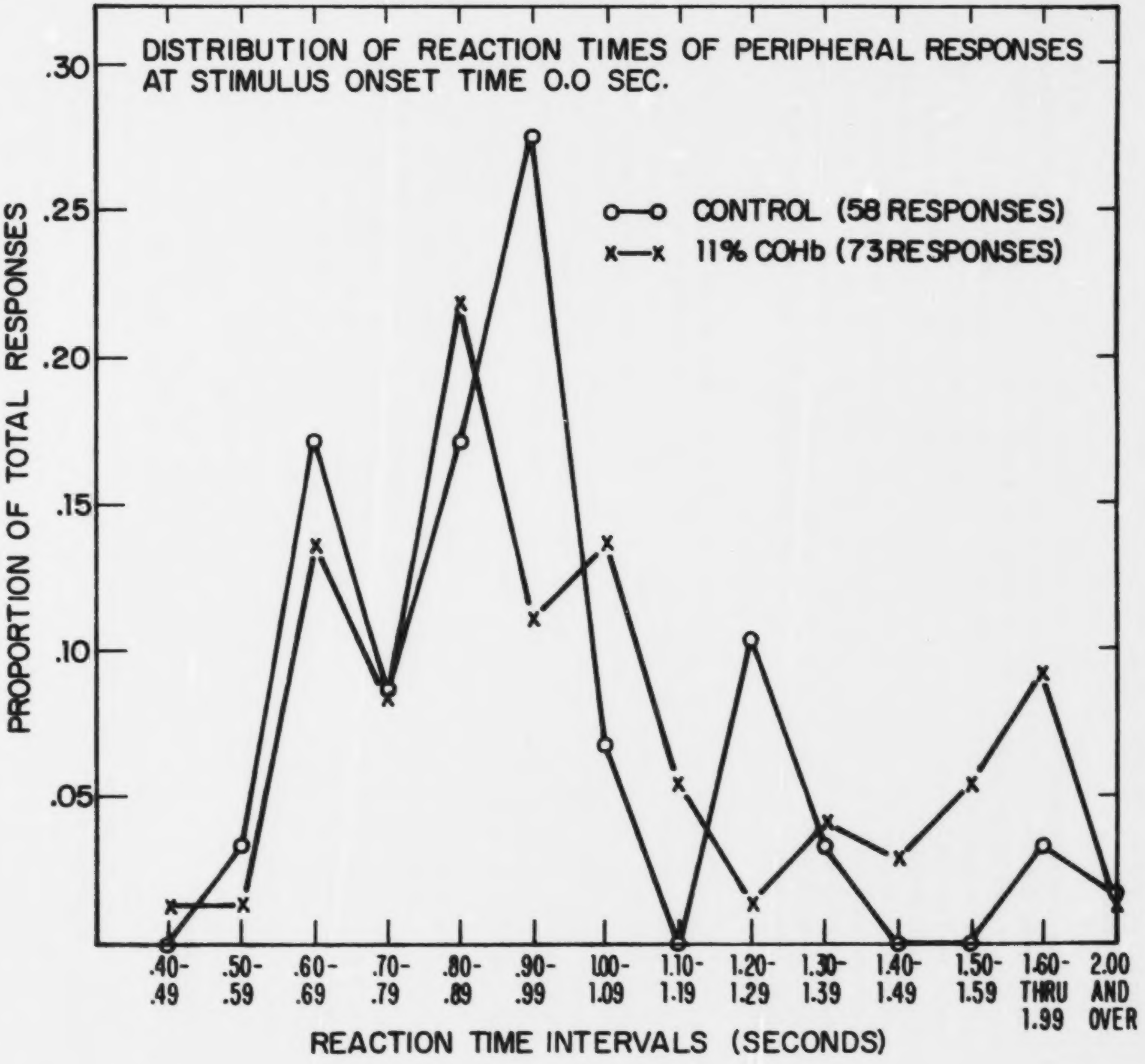

DISTRIBUTION OF REACTION TIMES OF PERIPHERAL RESPONSES AT STIMULUS ONSET TIME 0.0 SEC.
CONTROL (58 RESPONSES)
11% COHb (73 RESPONSES)
PROPORTION OF TOTAL RESPONSES
.30
.25
.20
.15
.10
.05
.40-.49
.50-.59
.60-.69
.70-.79
.80-.89
.90-.99
1.00-1.09
1.10-1.19
1.20-1.29
1.30-1.39
1.40-1.49
1.50-1.59
1.60-THRU 1.99
2.00 AND OVER
REACTION TIME INTERVALS (SECONDS)

Figure 17.

the next interval lower than in the corresponding control plot, i.e., from .60-.69 sec. to .50-.59 sec. This may reflect a previously mentioned influence of familiarity with the test, or practice, resulting in shorter response times in the "neutral" areas of the test and possibly obscuring any effects of CO in more critical ones.

The distributions were also examined for the possibility, under CO, of an increase in the frequency of excessively long response times. This possibility was suggested by the preliminary findings in a concurrent study at Harvard on the effects on performance of marihuana and alcohol in which the Complex Reaction Test was also used. Accordingly, tables were set up of the proportions of the distributions of response times at each time point which, respectively, reached or exceeded reaction times of 1.00, 1.20, 1.30, 1.40, 1.50, 1.60, and 2.00 seconds, for both the control and CO data. Under both test conditions it was apparent that instances where 10% or more of the reaction times were longer than 1 second were concentrated in stimulus times near the time of simultaneous onset. The data for control and 11% COHb at time points 1.6 to .4 are shown in Table 10.

A consistent pattern of increased frequency of the longer reaction times under CO is not apparent. Only the increases at 0.0 time were statistically significant (at .05 or less) in the cases of responses 1.0 sec., 1.3 sec., and 1.4 sec. or longer. None of the differences in the direction of decreased frequency of the longer reaction times under CO reached significance. However, a satisfactory assessment of the significance of differences in this table is difficult because of the small absolute numbers of prolonged responses and variations in the totals of the distribution being compared.

The data relating to control and 17% COHb were analyzed in a similar manner. In this case, significant increases under CO were observed at stimulus time 1.8 in regard to the reaction times exceeding 1.0, 1.1, 1.3, and 1.4 sec. and with increase of borderline significance at 1.2 and 1.5. Borderline significance was also indicated for an increase in times longer than 1.0 sec. at stimulus time .3. Again, none of the differences in the direction of fewer prolonged reaction times were significant. Also, the rare instances of exceedingly long reaction times, i.e., 2.0 or greater, seem to be scattered through the stimulus time range and not to differ in frequency between CO and control conditions.

A further treatment to provide larger cell frequencies by combining the data for two or more adjacent presentation times would have been desirable in order to permit more precise comparisons and estimates of significance by Chi-Square techniques. This, however, could not be carried out within the resources of the project, and verification of the slight suggestion that prolonged peripheral response times may be more frequent under certain stimulus conditions at these levels of COHb awaits further investigation.

Table 10

Prolonged Reaction Times to Peripheral Stimuli as Percentage of Responses Which Exceed Selected Times at Stimulus Presentation Times .4 Sec. Before to .4 Sec. Following Central Stimulus Time

		Reaction Time Reached or Exceeded							
Stimulus Time	Test Condition	1.00 Sec.	1.10 Sec.	1.20 Sec.	1.30 Sec.	1.40 Sec.	1.50 Sec.	1.60 Sec.	2.00 Sec.
1.6	Control	13.2	8.3	6.4	4.5	3.6	3.6	0.9	0.9
	11% COHb	8.0	8.0	6.0	4.0	2.0	1.0	1.0	0
1.7	Control	17.9	13.4	13.4	10.0	8.9	6.7	4.5	1.1
	11% COHb	19.2	13.5	10.1	9.0	5.6	2.2	2.2	1.1
1.8	Control	20.2	18.8	14.6	8.4	7.0	5.6	4.2	1.4
	11% COHb	28.6	24.9	19.9	12.4	8.7	6.2	3.7	0
1.9	Control	33.2	20.0	16.0	12.0	8.0	8.0	6.0	2.0
	11% COHb	32.6	27.3	23.1	16.8	10.5	8.4	6.3	0
0.0	Control	25.6	18.8	18.8	8.5	5.1	5.1	5.1	1.7
	11% COHb	42.0	28.4	23.0	21.7	17.6	14.9	9.5	1.3
0.1	Control	27.1	19.6	10.5	6.0	4.5	3.0	1.5	0
	11% COHb	25.9	13.6	13.6	7.5	6.0	4.5	4.5	1.5
0.2	Control	13.2	6.5	3.2	3.2	1.6	1.6	0	0
	11% COHb	24.0	12.8	8.0	6.4	4.8	3.2	3.2	1.6
0.3	Control	25.6	15.8	10.9	8.5	4.8	2.4	2.4	0
	11% COHb	17.1	11.8	9.2	7.9	3.9	2.6	1.3	0
0.4	Control	12.0	9.6	7.2	6.0	4.8	2.4	1.2	0
	11% COHb	11.1	9.9	7.4	6.2	3.7	1.2	1.2	0

D. Dark Adaptation and Glare Recovery

1. Test Procedures

Among the critical visual tasks which drivers encounter is the ability to see after exposure to high levels of illumination at night, a condition that arises primarily from the headlights of oncoming vehicles. The effects of such glare tend to disrupt the visual photochemical system. Although glare has been studied under a variety of conditions by investigators at this School, little has been done to analyze the amount of time necessary to achieve the pre-existing levels of dark adaptation. In order to study this effect, two test procedures were available.

In the first of these, a visual discriminometer was used to investigate recovery from light shock (see Figure 18). The subject was seated in a light-tight compartment and used his left eye to locate a red dot in the center of the visual field. He was then presented with a pre-exposure light source of 2000 ml for 3 minutes, after which the light is turned off, and the subject attempted to relocate the red dot. While fixating on this dot, a 1° test field, located 7° to the left of the fovea, was illuminated with light flashes of 1/25 of a second. Threshold values were obtained by increasing the intensity of these light flashes until the test field was just seen by the subjects. The threshold values were recorded in log luminance-millilamberts, and were taken first at less than one minute after the exposure to the light source, then at approximately one minute intervals until final thresholds were obtained at around 12 and 13 minutes. The resulting values were recorded in tabular form and plotted as curves of the dark adaptation of each subject under each test condition.

After these final threshold dark adaptation values were obtained with the visual discriminometer, each subject then had introduced into his visual field a bright flash of light of one second duration. His 1° test field was then illuminated with 1/25 of a second flashes of light in rapid succession. The elapsed time for the subject to first see this test field illuminated by the same light value as that of his final dark adaptation threshold was then recorded as his glare recovery time.

In the second test for glare recovery, a Biometrics glare testing device was utilized. Each subject was first tested for his glare threshold by his ability to identify Landolt rings (circles with gaps at the top or bottom, right or left) under progressively lower levels of illumination. Once this threshold was obtained, a glare source was turned on in the subject's field of view, immediately to the right of the testing device. After looking at this glare for 15 seconds, the subject then again attempted to identify the gaps in the Landolt rings until three successive correct determinations were made. The time required to return to his original threshold was then recorded.

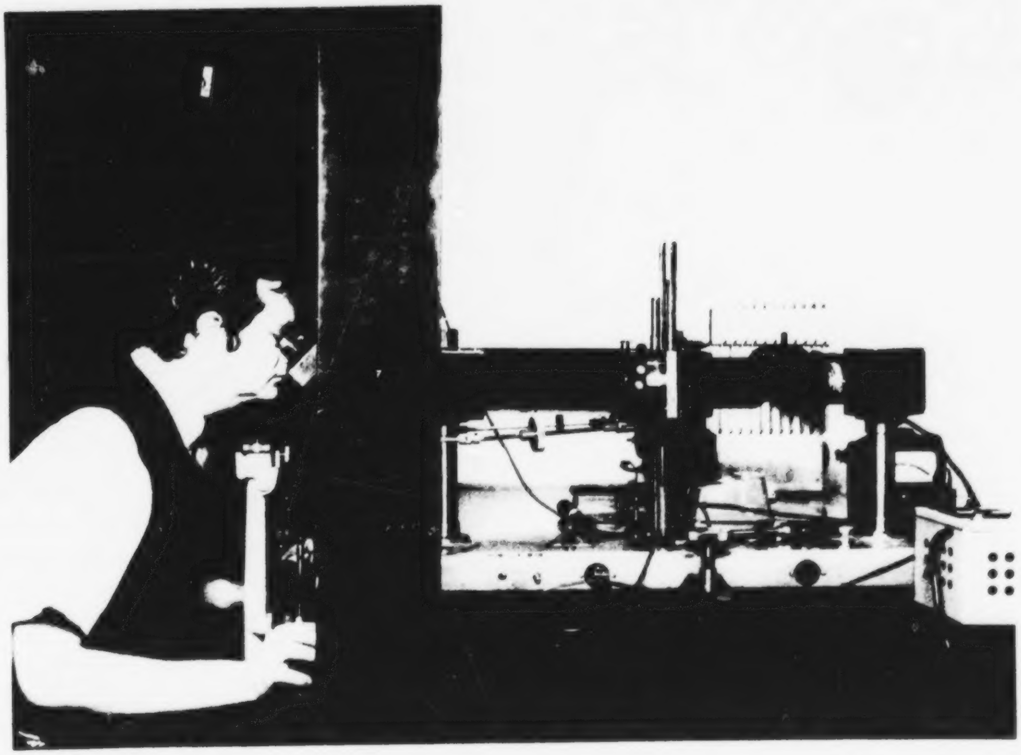


Figure 18. Visual discriminometer and subject. Testing is carried out in darkness while the subject is in the experimental enclosure.

2. Results

Data for dark adaptation threshold values are available for 25 subjects over the time range from approximately 30 seconds to 13 minutes at one-minute intervals after exposure to the bright light source. For the first 9 of these subjects, data are available from each of four test sessions, those at 17%, 11% and 6% COHb, and control-or less than 4% COHb. After these 9 subjects were run, two changes were made in the experimental design. First, the 6% COHb level was eliminated since preliminary results clearly indicated an inability to differentiate between this level and the control condition. Secondly a pretest was added to each of the remaining three sessions, or 11% and 17% COHb, and control. The pretest was always given prior to the gassing procedures.

There are thus two different sets of results for comparison. First, the interday comparisons of the results from each of the three sessions, or: 17% COHb vs. control, 11% COHb vs. control; and 17% COHb vs. 11% COHb. These data are available for all 25 subjects. The second set of results contains the intraday comparisons of the pretest-test results. Here the pretest (or before gassing) results are compared with those of the same test administered after the gassing procedures. The comparisons here are: 17% COHb, pretest vs. test; 11% COHb, pretest vs. test; and control, pretest vs. test. These data are available for 16 of the subjects.

The results for the interday comparisons of the effects of CO on dark adaptation as measured by the discriminometer are as follows: For the final dark adaptation threshold values obtained at about 13-14 minutes after bright light exposure, there were no statistically significant differences between the results of the three CO exposure groups when evaluated by means of the paired "t" test. This holds true for 17% COHb vs. control; 11% COHb vs. control; and 17% COHb vs. 11% COHb. Overall mean differences were slight, and changes in the direction of the difference between subjects were common. (The highest level of significance found was $P < .5$, as opposed to the commonly accepted minimum level for statistical significance of $P < .05$).

The intraday pretest-test comparisons were then made. Here as noted, we are comparing the results of the dark adaptation threshold values of subjects as measured before and after gassing on the same day. For the final dark adaptation threshold values, a statistically significant difference (paired "t" test, $P < .02$) was observed between 17% COHb pretest-test results. The 11% COHb pretest-test results showed no statistically significant results, though the control pretest-test comparisons did show such a difference.

Since the pretest-test comparisons clearly demonstrated a greater likelihood of establishing significant differences between no-CO and CO conditions, it was decided to further evaluate the dark adaptation data at <1, 4, and 10-minute intervals after light exposure. The less-than-one minute interval was selected since this was the first determination made after light exposure, while the four-minute interval represents the time at about which the curve of the cone function of the eye for dark adaptation is beginning to flatten out. The 10-minute interval was selected as roughly around the midpoint of the rod function for dark adaptation. The results were as follows:

At the 1-minute interval, neither 11% COHb pretest-test comparisons, nor the 17% pretest-test comparisons showed statistically significant differences (paired "t" test) for dark adaptation. However, the control pretest-test difference did just attain statistical significance ($P < .05$). It is interesting to note here that the direction of the difference shows a higher light value for the pretest condition, a reversal of the pattern that holds fairly consistently elsewhere.

At the 4-minute intervals there were no statistically significant differences between any of the pretest-test conditions, though the 17% COHb level came closest at $P < .1$. At the 10-minute time interval neither control nor 11% COHb pretest-test comparisons showed statistically significant differences, but the 17% COHb pretest-test comparison was significant ($P < .05$).

Figures 19, 20 and 21 demonstrate graphically the dark adaptation curves and the values in log luminance-millilamberts at each time interval from approximately 30 seconds to 14 minutes after lighr exposure. These curves are based on the averaged values for all subjects for which pretest-test data are available. The general tendency towards higher values, i.e., more light needed, can be noted for both 17% COHb and 11% COHb pretest-test conditions. This distinction is less marked for the control condition.

To summarize, the results of the dark adaptation values obtained on the same subjects under different CO conditions on different days do not seem to yield significant differences. This could be due to the fact that interday variability, for whatever reason, is so great that it overrides any effect of the CO administered. This, of course, would only be true if the effect of such variables were reasonably randomly distributed in this small sample - which may or may not be the case. If there is a CO effect operating here, it may be cancelled out by these other variables.

Alternatively, it is possible that the test is not a sufficiently sensitive one to be able to distinguish between the effects of such relatively low levels of CO. This would not appear to be the case for two reasons: (a) the test has, in the past, been successfully used to differentiate between the effects of lower levels of CO and no CO, and (b) as the result described above demonstrate, the test does indicate some sensitivity on an intraday pretest-test basis.

Here, interday variability within and between subjects is removed but, although statistically significant differences do appear with 17% COHb pretest-test conditions, they are also found under the control pretest-test conditions. It seems, therefore, that there may be some factor or factors in the gassing procedure itself that influences dark adaptation in the subjects. This could be fatigue, motivation, altitude, boredom, discomfort, time of day, blood-sugar

Dark Adaptation

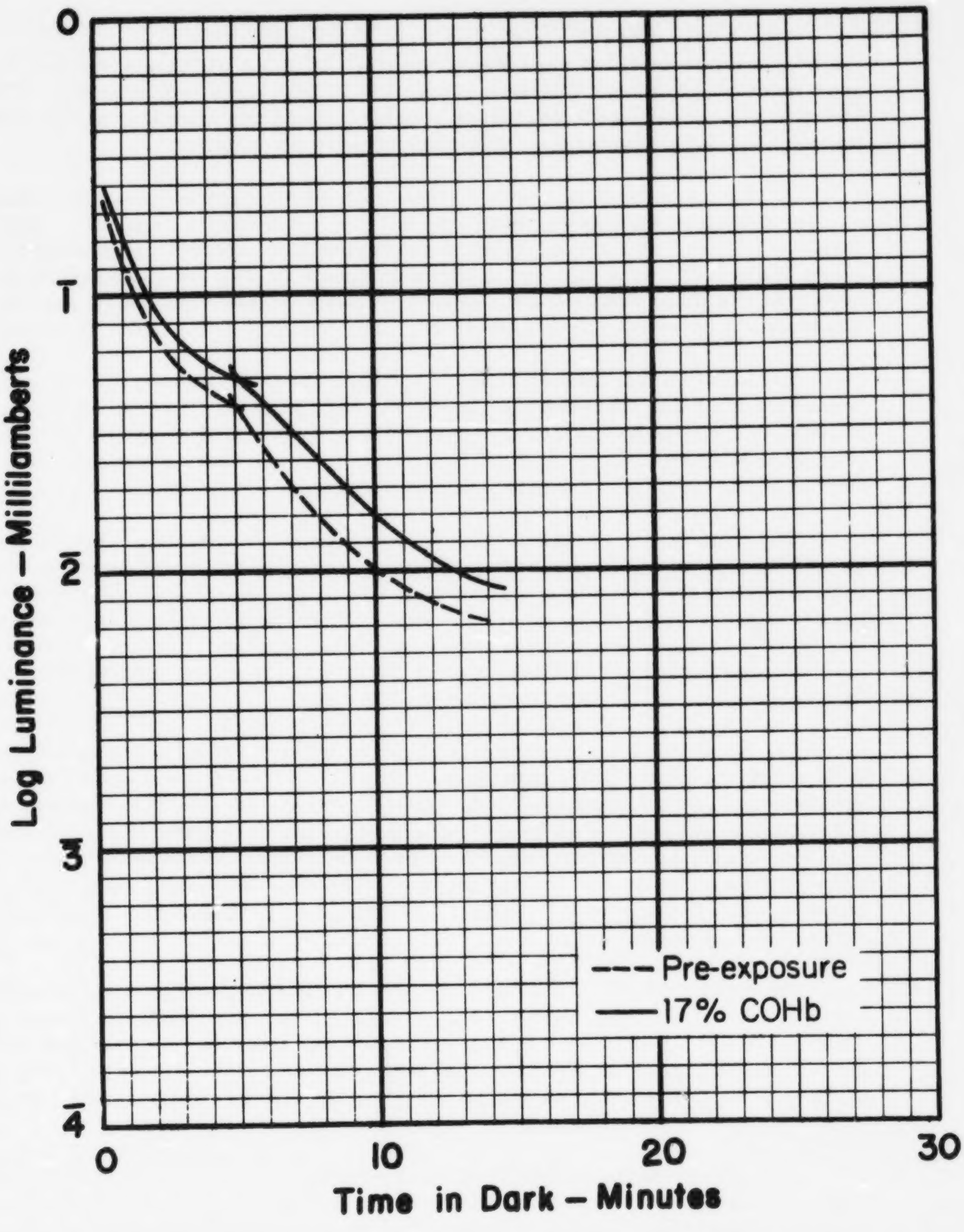


Figure 19. Dark adaptation curves for 15 subjects before exposure to CO and after exposure with 17% COHb. The first part of the curve depicts the cone function, the second part the rod function.

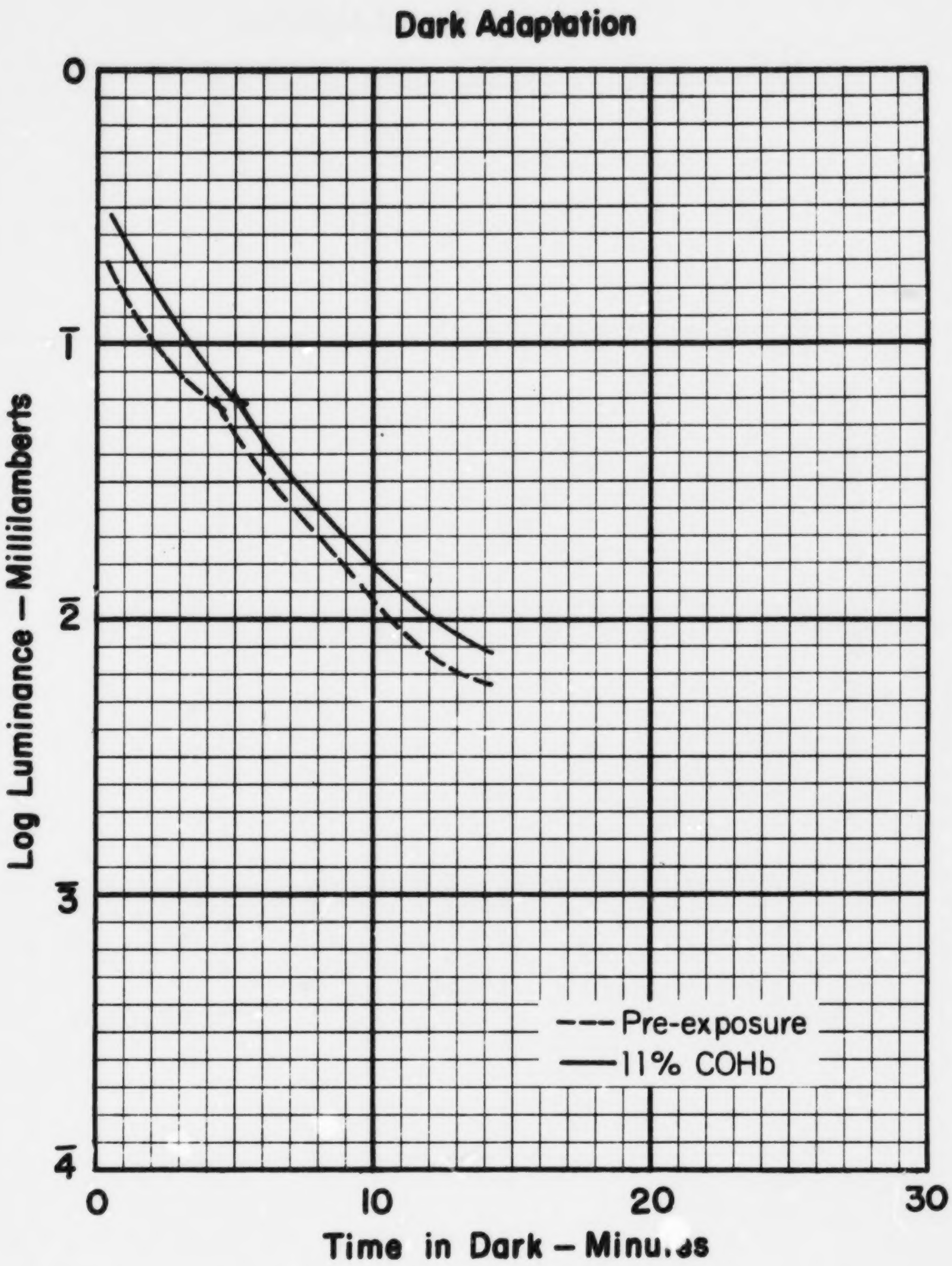


Figure 20. Dark adaptation curves for 14 subjects before exposure to CO and after exposure with 11% COHb. The first part of the curve depicts the cone function, the second part the rod function.

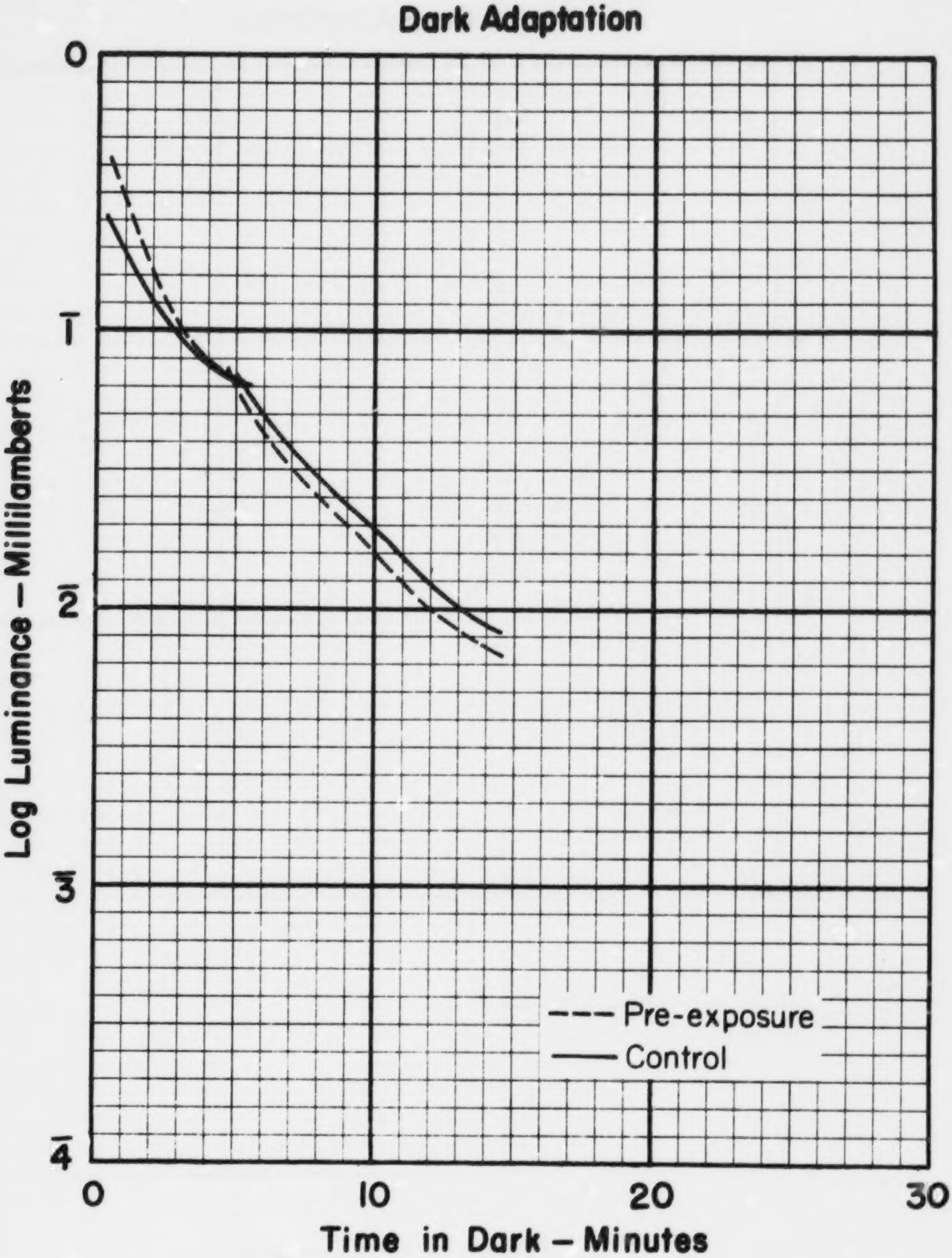


Figure 21. Dark adaptation curves for 15 subjects before and after exposure to a CO placebo (Control). The first part of the curve depicts the cone function, the second part the rod function.

levels, etc. - any of a variety of possible variables. (It should be remembered that, of necessity, the test is always given about one and one-half hours after the pretest.) In addition, while the subjects were not highly trained, or specially motivated, they were fully familiar with, and practiced in, the task expected of them, and they appeared reasonably well-motivated. It should also be observed that since pretest results generally and fairly consistently required less light than the test results, the differences could hardly be attributed to training or practice.

In other words under these testing conditions, and with these subjects, there is little indication that COHb levels of up to 17% COHb have any significant effect on dark adaptation.

For glare recovery, i.e., the time, in seconds, required to return to the previous final dark adaptation level after exposure to a one-second bright flash of light, the results are as follows: When interday comparisons were made, i.e., 17% COHb day vs. control day, 11% vs. control, or 17% vs. 11%, none of the results approach statistical significance ($P < .6$ by paired "t" test, the highest association).

When pretest-test values were evaluated, the results approached (but did not achieve) statistical significance more closely as follows: 17% COHb, $P < .3$; 11% COHb, $P < .2$; control, $P < .1$. Clearly there is no suggestion at all here of a CO-related effect on glare recovery.

E. Peripheral Vision

1. Test Procedures

Since the driving task involves the ability to assimilate a variety of visual stimuli emanating from different parts of the environment, it is clearly important to investigate the ability to discriminate or recognize stimuli in the central and peripheral visual fields. In this test the subject was seated with his eyes positioned 20 inches from a translucent screen in a darkened experimental chamber. Using his left eye he fixated on a lighted dot in the center of the screen, his other eye covered by a patch. With a Kodak Ektagraphic Carousal Projector, 60 slides were presented to the subject. On each slide there were four dots: half of the slides have the dots arranged in a square, half in a diamond. In 20 of the slides the dots are presented so that they fall 10° from the subject's point of central fixation. Twenty slides have the dots at 20°, and a third group of 20 at 30°. The slides are mixed and presented in random order, each for 0.0125 second. The subject's task was to report the number of dots seen of the four dots that were always presented. Figure 22 shows the test apparatus.

2. Results

Twenty-two subjects completed this test under conditions of 17% COHb, 11% COHb, and control, each test taken on a different day. No statistically significant

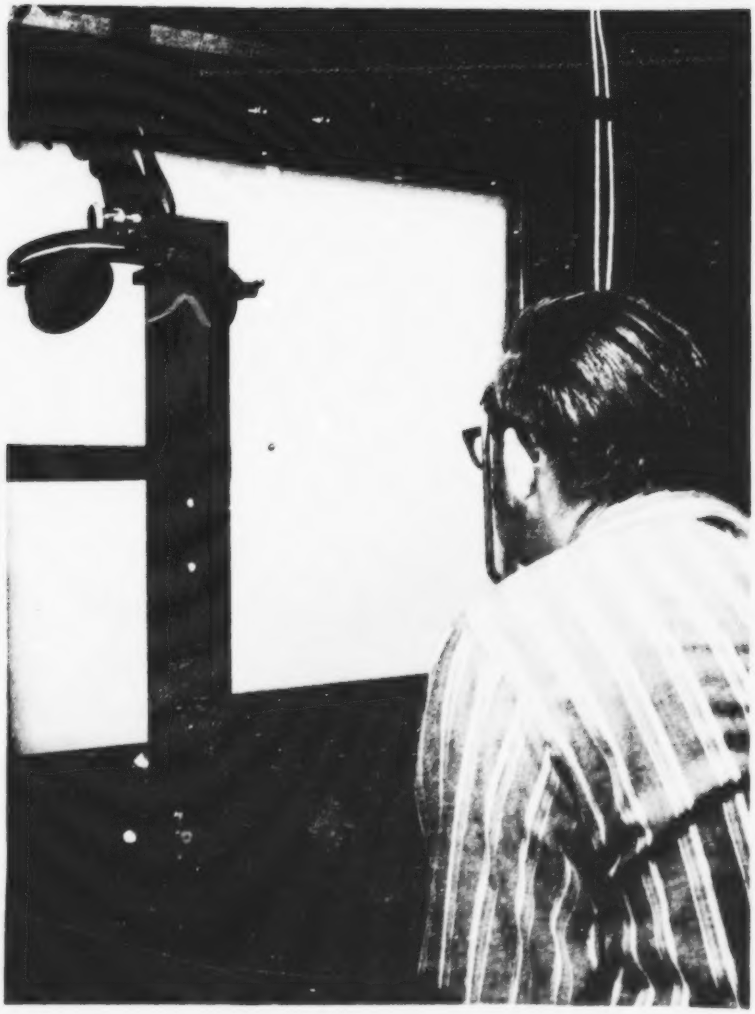


Figure 22. Subject in position for peripheral vision test. Dot patterns are projected on screen to left in darkened booth.

differences were found between any of the CO levels for the slides with dots presented at 10°. Almost all subjects saw most of the dots most of the time, regardless of CO level. Similarly, no statistically significant differences were found between any of the CO levels and the 30° slides. Here, most of the subjects missed most of the dots most of the time - regardless of COHb level.

For the target patterns presented at 20°, however, the results were different. There was an increase in mean number of dots missed for the 22 subjects from control to 11% to 17% COHb. The 11% vs. control comparisons were not statistically significant, but the 17% vs. control results were. When total numbers of dots missed were compared (with the paired "t" test), the significance level was $P < .05$. If the total numbers of slides presented in which any dots were missed were compared, the level increased to $P < .01$.

There thus does appear to be some sort of a CO-related decrement here in near peripheral vision, though the extent of the data does not permit any firm conclusions in this regard. The 10° test was too easy, and the 30° test too difficult. Future tests in this area should vary the intensity of illumination of the presented targets, as well as their size, exposure time and position, until a more critical and sensitive set of conditions are found. The more important area is likely to be that farther out to the periphery of the field of vision.

F. Depth Perception

1. Test Procedures

Depth perception, which could be of considerable importance to the driving task was evaluated by means of a standard Verhoeff apparatus. In this equipment a 1/2 by 2 inch illuminated opening contained three vertical bars which varied in width and in depth in eight different presentations. The subject was asked to determine which of the bars were closest or most distant.

2. Results

The data from the depth perception test utilizing the Verhoeff apparatus can be summarized as follows: Each subject was presented with 8 successive determinations, his score expressed as a fraction of those correct, e.g., 8/8, all correct; 4/8, 4 incorrect. Of the first 10 subjects run, 8 scored 8/8 on control and at all COHb levels, while 2 subjects, obviously with poor depth perception, had equally poor scores, i.e., 1/8, 2/8, 3/8, etc., both at the control condition and at all three COHb levels. (A similar pattern of results were found on subjects run with and without 4 ounces of 80° alcohol.) While the test is apparently a good measure of a subject's binocular stereopsis, it obviously was not able to differentiate the effects of relatively low levels of carbon monoxide (up to 17% COHb) - at least under these conditions with this equipment. The test was, therefore, eliminated.

V. Driving Experiments

A. Introduction

The purpose of the driving experiments was to attempt to detect and measure certain changes in actual driving performance that may take place after exposure to carbon monoxide. These experiments were conducted on an unopened, divided highway utilizing a visual interruption apparatus as a measuring tool in a 1971 Plymouth Fury test vehicle.

Specifically, the experiments were designed to measure any decrement in the driver's performance in a task which is fundamental to the driving process: the processing of visual information required for positioning of the vehicle on the roadway. By standardization of car and road, and specially designed apparatus to control the amount of visual attention the driver could devote to the task, these experiments involved a driving situation that was both realistic and safe and provided objective measures of driver performance.

Experimental attempts to measure the performance of drivers while operating vehicles on the roadway have so far been limited in their results. It is difficult to carry out controlled experiments without the driver's being aware of the measurement procedures and being influenced by them. Furthermore, the demands on the ability of the driver to process the incoming information vary greatly. At times the demands are considerably below his full capacity; at other times his capacity may be exceeded. Some of the needs for information relate to tasks in the immediate and ongoing control of his vehicle, for example, in lane holding, maintaining distance from a leading car, steering, braking, or accelerating in relation to other traffic or roadway hazards. Thus, one approach to the measurement of performance may be based on the information processing inherent in driving, utilizing the techniques of information theory.

In the present project a technique of intermittent visual time sampling was used. The field of view of the driver is interrupted systematically as he operates a vehicle on the roadway. This was accomplished by a helmet-mounted visor which alternately dropped to occlude the driver's vision at controlled frequencies and duration (the Visual Interruption Apparatus, or VIA). In previous experiment conducted on closed road systems and unopened sections of interstate highways, it was found that sufficient information for error-free lane holding operation was obtained if drivers viewed the road for a period of one-half second at 2-second intervals at a speed of 60 mph, at every 4 seconds at 25 mph, and every 9 seconds at 5 mph. The records were obtained under conditions where (1) the occlusion rate was controlled by the experimenter and vehicle speed by the subject, and (2) where vehicle speed was controlled and the driver actuated the occlusion device as needed. The results were used to develop a mathematical model which related the driver's informational content of the roadway in "bits" per mile, the speed of the vehicle, and the driver's estimates of his own uncertainties. This work was subsequently extended to include the information-processing demands of car-following and passing, and driving under normal traffic conditions.

The Visual Interruption Apparatus itself consists of a helmet with an attached face shield which can be moved up and down by means of a gas-operated piston mounted on the helmet. The piston can be operated by a solenoid valve whose switch is accessible to the driver's left foot, or alternatively by an automatic timing sequence. The shield is designed to be non-transparent, but translucent. During testing, the normal position of the shield is down (the occluded position). Depressing the solenoid switch drives the helmet into the up (seeing) position for a fixed viewing time before the visor closes again. (See Figures 23, 24 and 25.) Based on previous experience, a viewing time of approximately 0.5 sec. has been found to be suitable. (For a more detailed description of the VIA see Senders, et al., 1967, 1969.)

B. Selection of Subjects

All subjects used in the driving experiments were drawn from the pool of those who have already participated in the laboratory phase of the experiments. In addition to the health requirements previously described (see Section II), additional screening for the driving phase ensured that all subjects: (a) had a current driver's license; (b) had at least 50,000 miles driving experience; (c) had no more than two reportable accidents for six years; (d) had no more than three moving violations for two years. (e) Finally, no one who disliked driving was selected as a subject.

C. Roadways

Two different roadways were used in the driving experiments. The first was a closed loop, two-lane winding roadway in the Arnold Arboretum in Boston. Initial experiments establishing testing procedures with the visual interruption apparatus were carried out on this roadway from which all other vehicular traffic was excluded. The winding nature of the road, however, plus the occasional presence of pedestrians and bicycles, made it undesirable for the basic driving experiments. For this purpose we used a completed but unopened segment of Interstate 95, a limited access eight-lane divided highway in Danvers, Massachusetts, about 20 miles from the School of Public Health. The test course was 1.9 miles in length and consisted of the two middle lanes of the northbound segment of this highway. During the testing no other vehicles or persons were present on the highway.

D. The Test Vehicle

The test vehicle, a 1971 Plymouth Fury sedan was equipped with a number of options, some primarily for safety purposes, and some to facilitate carrying out the experimental conditions. In all cases the intent was to keep the vehicle as "ordinary" as possible insofar as the subjects were concerned. The special equipment on the test vehicle is listed by description and by manufacturer's code in Appendix F. Certain other equipment was necessary to accommodate the experimental apparatus and experimental protocol. For example, the electrical system of the vehicle had to supply additional power for the timers and recorders,

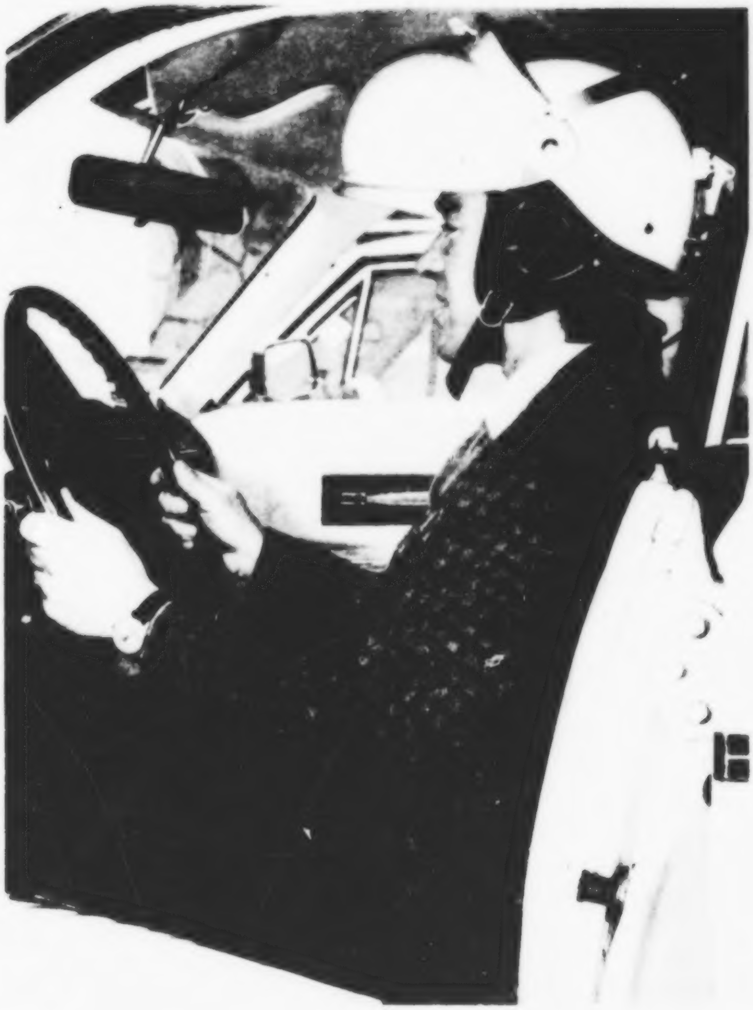


Figure 23. Visual Interruption Apparatus: visor raised for full road vision.

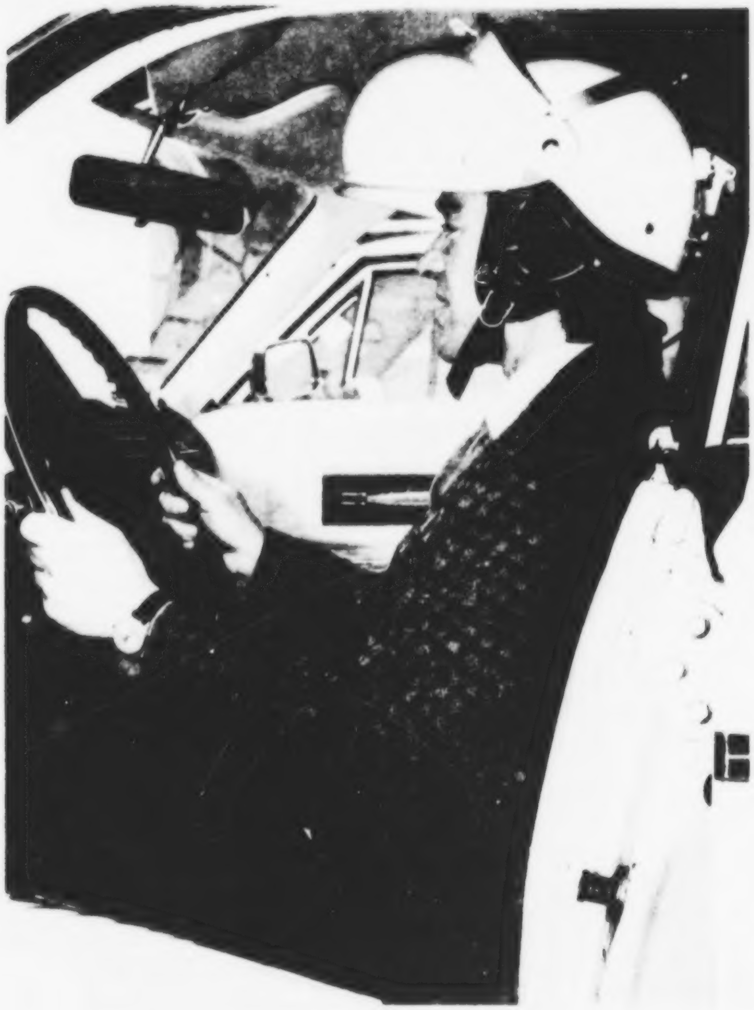


Figure 23. Visual Interruption Apparatus: visor raised for full road vision.

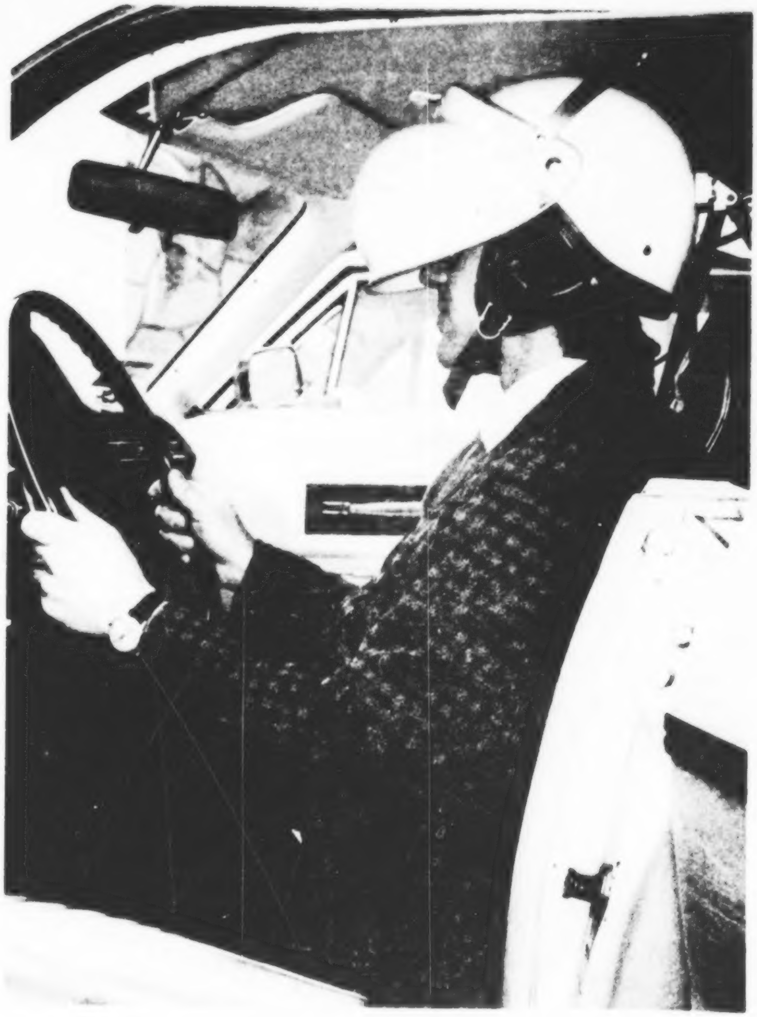


Figure 24. Visual Interruption Apparatus: visor lowered for occluded vision.

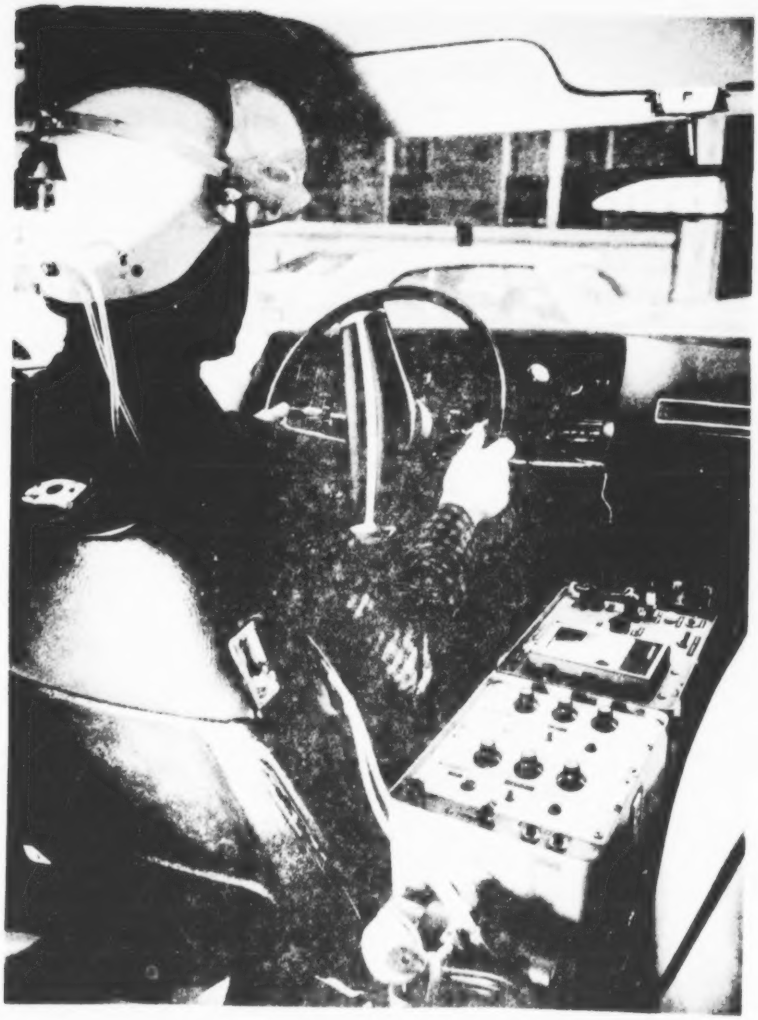


Figure 25. Overall view of Visual Interruption Apparatus and control and recording equipment (lower right). Plastic tubing supplies and vents the compressed CO_2 which operates the helmet visor.

and these requirements were met by a larger 70-amp-hour battery and 60-amp max. capacity alternator, monitored by a 60-amp calibrated ammeter. A magnetic tape recorder was used for voice recording. The vehicle power plant had to produce very low amounts of CO when operated at the speeds expected during the experiments, since the car was to some extent exposed to its own exhaust.

Other special features included a seat back from a 1970 Plymouth bucket seat, with a non-integral head restraint, which was installed on the driver's seat to allow shorter test subjects to sit normally without interference from the actuating cylinder on the VIA. Inertia reel shoulder harnesses were also installed. Aside from improved convenience, the inertia reels provided a feeling of freedom of motion similar to that afforded by not wearing a shoulder harness. Since most of the driving population choose not to wear seat belts, let alone shoulder belts, this freedom of motion is important in making the subjects feel comfortable in the experimental vehicle. A dry chemical fire extinguisher was installed in the passenger compartment.

In addition to the data obtained by the VIA apparatus, steering-wheel movements and measures of vehicle position in lane were recorded. Steering-wheel position was measured by means of a potentiometer mechanically connected to the steering column. The position of the vehicle in the lane was monitored continuously with scanning photocells contained in each of two units mounted on the vehicle directly in front of the two front wheels. These sensors detected each crossing of a white lane marker. A Rustrak event recorder was used for recording helmet usage (number and time interval), and lane-holding errors. Steering wheel movements were traced on a Rustrak potentiometric recorder. The cassette equipment in the vehicle was used to play back a standard instruction tape to all subjects.

E. Experimental Procedures

Each subject in the driving experiments participated in three separate sessions, the first of which was a training session of several hours duration devoted to familiarization with the driving task, and the use of the visual interruption apparatus. The second and third sessions lasted approximately eight to nine hours each, from the time the subject first appeared in the morning for gassing until he was dismissed after having his COHb level reduced to 6% or less.

During both the training and the actual driving runs on the test course, the subject was required always to maintain a path within the normal 12-foot marked lanes on the highway. To accomplish this, he had to select a viewing frequency to match the fixed speed conditions of the vehicle. In essense, the driver was required to stay in lane exactly as if he were able to view the road continuously. Occlusion data were obtained in runs at two speed levels, 30 and 50 mph, and each subject drove at both speeds on each day. These two speed levels permitted interaction effects between CO and speed to be assessed.

In previous experimental programs, experience was gained with both fixed-vehicle-speed, subject-controlled occlusion conditions, and with subject-controlled vehicle speeds and fixed occlusion rates. Subjectively, it was observed that the variable-occlusion condition provided the driver with more immediate control over his perceptual environment. The response time of the visor to the depression of the foot switch is virtually instantaneous. On the other hand, the vehicle can be considered as relatively slow to respond to minor changes of acceleration or brake pressure. There is evidence to show that the driver even perceives straight and level road as possessing a variable information rate. Consequently, the fixed-vehicle-speed, subject-controlled-occlusion condition is likely to be the more desirable of the two experimental modes. (Senders, et al., 1967, 1969)

1. Training Sessions. Subjects were trained in pairs. After reporting to the Harvard School of Public Health in the morning, the subjects were driven in the test vehicle to the Danvers course. During the one-half hour trip, the subjects listened to a pre-recorded tape which described the experiment they were about to participate in (the text of this tape is presented in Appendix G). After this introduction the experimenter answered any questions and then explained in more detail the experimental task, the operation of the Visual Interruption Apparatus, and all other experimental instrumentation in the vehicle.

After arriving at the test site, the experimenter first drove over the course to familiarize the subjects with it, noting the starting and finishing points, and explaining the operation of the vehicle's automatic speed control. The experimental equipment was then checked, and the lane sensors mounted on the vehicle. The experimenter donned the VIA and drove a test run to demonstrate the operation of the helmet. The first subject then took his place in the driver's seat, adjusted it to his normal driving position, adjusted his lap belt and upper torso restraint, and positioned the left foot switch which raised the visor of the helmet. He started driving and locked in the automatic speed control at 30 mph. The experimenter activated a switch which lowered the visor over the subject's eyes. From this point on the visor remained down until the subject actuated his foot switch which raised the visor for 0.5 sec. of full vision.

Throughout the training session the subject was instructed to take as many looks as needed, but no more, in order to keep the vehicle at all times within the 12-foot width between the lane markers. Errors in lane holding were indicated by the sensors which activated a light on the instrument panel. The subjects were forewarned that during the later tests crossing the lane markers would cause the run to be aborted and restarted from the beginning. The subject then made as many runs over the 1.9 mile course as necessary to make his driving largely, though not necessarily completely, error-free. At this point he began a series of 8 runs, 4 north and 4 south over the course at 30 mph. These runs duplicated those that he would undertake in the two subsequent "data" sessions (during the training sessions all data were recorded, but were not necessarily intended for use in the analyses).

The second subject then underwent the same training procedures for his

30 mph runs. Following a lunch break, the first subject began a series of eight runs at 50 mph, after which the second subject did the same. At this point most subjects were found to be essentially error-free in their driving performance, that is, they were able to keep their vehicle within the lane markers with a minimum number of "looks". Where this was not the case, additional runs were made until the experimenter was satisfied with the subject's performance. No training sessions, or experimental runs, were ever carried out during rain, snow, wet roads, high wind, poor visibility, or any other conditions that might adversely affect driving performance or provide significantly different driving conditions from one day to the next.

2. Experimental Sessions. Once the subjects were trained, the data-gathering runs were scheduled within the next several days. The same two subjects participated in pairs for these sessions. For the first day one of the subjects was randomly selected to breathe a carbon monoxide mixture (700 ppm) which raised his COHb level to 17%. The second subject concurrently underwent an identical breathing procedure, but was exposed to only room air. On the second day the exposures were reversed, i.e., the subject who had CO now received only air and vice versa. The experiment was double blind in that neither subject knew his exposure on either day, and the experimenters were equally unaware as to which subjects received CO on which days, until the conclusion of all data runs.

The general schedule for the road testing is outlined in Table 2. Initial procedures at the School were the same as those previously described for the laboratory sessions. However, upon arrival at the test track, a "refresher" is given to restore the subject's COHb level to 17%. For this purpose six 200 litre Douglas bags were used, 3 containing a CO mixture of 700 ppm for the CO subject, and 3 containing plain air for the non-CO subject. Breathing times on the Douglas bags were based on curves plotted from previous laboratory data for the rate of uptake of CO for the subject exposed to CO. The other subject was on plain air from a Douglas bag for an exactly equal length of time. Five minutes after the conclusion of the gassing, an alveolar sample was taken from each subject, immediately after which the first subject began his series of driving runs at 30 mph. Again accuracy in lane holding and error-free operation was stressed, consistent with the fewest number of "looks" with the helmet needed to achieve this goal. Errors in lane holding or any departures from normal in the operation of the equipment (failure of the speed control was the most common) caused the run to be recommenced.

A few minutes before the first subject finished his first run, the second subject was given his second CO "refresher", to again raise his COHb level to 17%. Similarly, just before this subject completed his 30 mph runs, the first subject had his second refresher and then began his 50 mph session. Finally, the second subject had his third refresher immediately before beginning his 50 mph runs. In all cases alveolar samples were taken 5 minutes after each CO refresher. Each subject began his driving run within about 5-10 minutes after breathing the CO mixture and was, therefore, very close to his intended 17%

COHb level at that time. Each driving session at 30 mph and 50 mph consisted of eight runs of 1.5 miles each, 4 in a northerly and 4 in a southerly direction.

Table 11

Daily Timetable for Road Testing

8:00 - 8:10	Arrive at School of Public Health, first alveolar sample taken
8:10 - 9:30	Subjects gassed
9:30 - 9:45	Blood and alveolar samples taken
9:45 - 10:30	Drive to test course
10:30 - 11:00	Set up testing equipment; subjects regassed
11:00 - 11:35	1st subject, 1st session, 30 mph
11:40 - 12:15	2nd subject, 1st session, 30 mph
12:20 - 12:45	1st subject, 2nd session, 50 mph
12:50 - 1:15	2nd subject, 2nd session, 50 mph
1:15 - 2:45	Pack-up; lunch; return to School of Public Health
2:45 - 4:15	Subjects degassed on O_2
4:15 - 4:30	Final blood and alveolar samples taken
4:30	Subjects released

Upon completion of the last run, the subjects returned to the laboratory, where alveolar and blood samples were taken. They were then placed on a breathing mixture of 99% O_2 and 1% CO_2 for approximately 80 to 90 minutes until the COHb level of the CO subject for that day was determined to be under 6%. At that time both subjects were dismissed.

F. Results

1. Analysis of Visual Occlusion Data

The time records of visor position provided the basis for measures of driver uncertainty in carrying out the task. Figure 26 shows a representative sample from the record of one subject during a driving run, with arrows indicating portions of the tracing representing periods of occluded and full vision. Viewing times were fixed at .5 second duration each. The numbers shown in the figure above the occlusion period portions of the tracing represent the time (in millimeters of tape) the subject could drive without vision of the roadway before having to activate the visor to obtain more information.

a. Number of Occlusions: The first analysis of the Visual Interruption Apparatus data provided a distribution of the numbers of occluded periods under

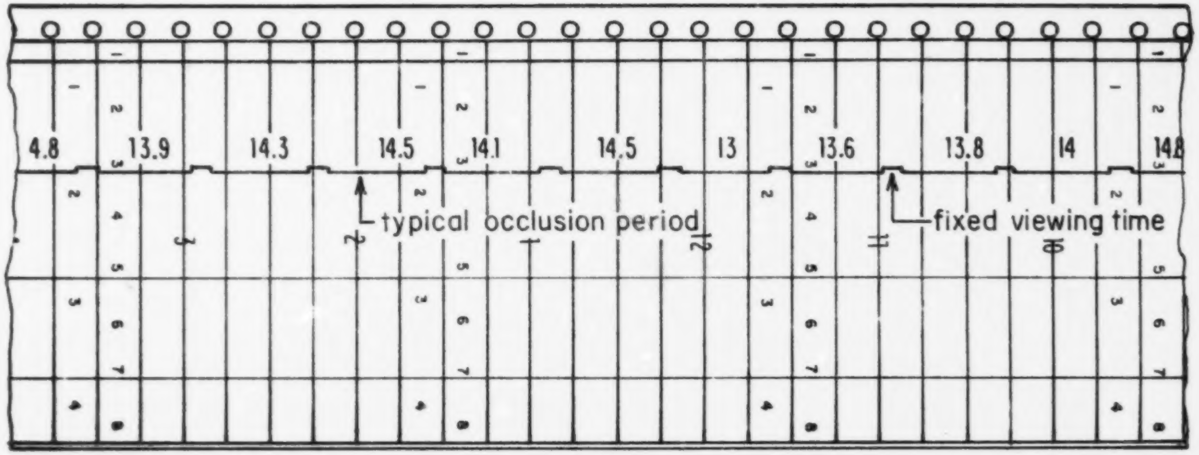


Figure 26. Sample of time record of Visual Interruption Apparatus (VIA) taken during one driving test. The fixed viewing times are 0.5 second in duration. Occluded periods vary in length according to the judgement of the driver.

the various experimental independent conditions. It became apparent that some of the observed variability in the total number of occluded time periods between and among subjects could be accounted for on the basis of variations in "locking-in" the automatic speed control at the exact experimental speed prescribed. Hence, for the fixed distance of the experimental route, there were unequal traversal times. Thus the total number of occluded time periods varied in part because of the time differences in test runs. (The speed control device was a production item designed for general use in highway cruising and proved to be only marginally useful for original experimental requirements.)

b. Percentage of Occlusion Time: For comparative analyses, it would be more useful to examine total occlusion time as percent of actual running time as a measure of performance. The occlusion time percentages were averaged for each subject's eight test runs under the various experimental conditions and the values are presented in Table 12.

c. Distance Traveled During Occlusion: A physical interpretation of average occlusion time percentage is possible by transforming the percentages into equivalent road distance measures. That is, the transformed data will represent the cumulative total road distance that the vehicle travelled while the subject's vision was obscured. In this transformation, the data were normalized in termsof an arbitrary one-mile base. These cumulative occluded distance (COD) results are presented in Table 13.

In general differences are apparent in the average values between the CO and no-CO runs. These differences, however, are small in magnitude and exhibit several reversals in the direction of change between the test and control conditions for both the 30 and 50 mph speeds. A paired t-test for a comparison of treatments (carbon monoxide vs. placebo) showed that there was no statistically significant difference as a result of the treatments for either the 30 or 50 mph speeds. However, although the COD values fell within a narrow range across subjects, variability in the individual subject's performance between days was apparent, complicating the determination of any effects of carbon monoxide on the performance measure in the above comparisons.

Having no previous experimental data regarding directional change in the arbitrary performance measure as a function of CO level, a pilot study was undertaken using the VIA procedures in which laboratory personnel participated, and in which alcohol was used as the experimental agent. In this study, subjects with a blood alcohol level of 0.10% consistently showed a decrease in the percentage of occlusion time compared with their own control results. It may be noted that these results were obtained from tests that were performed on the same day and, therefore, were not affected by the inter-day variability that seems to be prevalent in the CO data.

The randomization in the experimental design across days, and treatments, and with the 30 mph test always preceding the 50 mph test, made it possible to analyze the data for effects of CO while controlling inter-day variation. It was

Average Percent Occlusion Time as a Function of Gas Intake and Vehicle Speed

Subject	CO Condition and Speed	Percent Occlusion Time
G. F.	No-CO - 30	83.5
	CO - 30	84.4
	No-CO - 50	82.9
	CO - 50	83.2
W. F.	No-CO - 30	89.1
	CO - 30	87.4
	No-CO - 50	86.7
	CO - 50	83.1
J. L.	No-CO - 30	87.7
	CO - 30	88.4
	No-CO - 50	85.3
	CO - 50	85.1
H. A.	No-CO - 30	87.5
	CO - 30	88.4
	No-CO - 50	87.0
	CO - 50	88.0
O. R. - I	No-CO - 30	86.1
	CO - 30	85.5
	No-CO - 50	84.8
	CO - 50	84.9
O. R. - II	No-CO - 30	87.6
	CO - 30	87.5
	No-CO - 50	85.7
	CO - 50	84.8
P. L.	No-CO - 30	87.0
	CO - 30	88.8
	No-CO - 50	85.9
	CO - 50	86.4
J. D.	No-CO - 30	87.5
	CO - 30	88.6
	No-CO - 50	86.3
	CO - 50	86.1
A. C.	No-CO - 30	87.5
	CO - 30	89.6
	No-CO - 50	86.9
	CO - 50	86.0
M. H.	No-CO - 30	88.6
	CO - 30	87.4
	No-CO - 50	88.0
	CO - 50	88.0

Table 13

Changes in the Cumulative Distance Parameter as a Function of Gas Exposure

Subject	CO Condition and Speed	Cumulative Distance (ft)	Difference (ft) 30 vs. 50	Test Day
G. F.	No-CO - 30	4409	32	1
	No-CO - 50	4377		
	CO - 30	4456	63	2
	CO - 50	4393		
W. F.	No-CO - 30	4704	126	2
	No-CO - 50	4578		
	CO - 30	4615	227	1
	CO - 50	4388		
J. L.	No-CO - 30	4631	127	1
	No-CO - 50	4504		
	CO - 30	4668	175	2
	CO - 50	4493		
H. A.	No-CO - 30	4620	26	2
	No-CO - 50	4594		
	CO - 30	4668	22	1
	CO - 50	4646		
O. R. - I	No-CO - 30	4546	69	2
	No-CO - 50	4477		
	CO - 30	4514	31	1
	CO - 50	4483		
O. R. - II	No-CO - 30	4625	100	1
	No-CO - 50	4525		
	CO - 30	4620	143	2
	CO - 50	4477		
P. L.	No-CO - 30	4594	58	1
	No-CO - 50	4536		
	CO - 30	4689	127	2
	CO - 50	4562		
J. D.	No-CO - 30	4620	63	2
	No-CO - 50	4557		
	CO - 30	4678	132	1
	CO - 50	4546		
A. C.	No-CO - 30	4620	32	2
	No-CO - 50	4588		
	CO - 30	4731	190	1
	CO - 50	4541		
M. H.	No-CO - 30	4678	32	1
	No-CO - 50	4646		
	CO - 30	4615	11	2
	CO - 50	4604		

observed that, without exception, the percentage of occlusion time at 50 mph was less than that obtained at 30 mph on the same test day. This difference was found to be highly significant ($P < .001$) in a "t" test of paired differences. It would appear then that the subjects found the 50 mph speed to be the more difficult, i.e., they needed to view more of the road, hence they did not accumulate as much resultant occluded distance at the faster speed. The suggestion is that subjects adapted first to the requirement of the 30 mph runs, then attempted at 50 mph to replicate their performance at the lower speed driven earlier on the same day, the test itself, of course, remaining the same.

The greater difficulty of the task at the 50 mph speed relative to 30 mph is reflected in the COD measures as presented in Table 13 on the basis of data from tests carried out on the same day, with the 30 mph values serving as baseline. A two-way analysis of variance was then carried out on these data to determine any differential effect of CO. The results indicated a significant difference between the control and CO conditions which was significant at the .05 level. Thus the findings indicate that, under all conditions, the subjects required more viewing of the roadway to maintain accurate lane performance than at 30 mph. In addition, at 17% COHb subjects required even more roadway viewing at the higher speed relative to the lower speed, as compared to the control condition.

2. Analysis of Steering Wheel Reversal Data

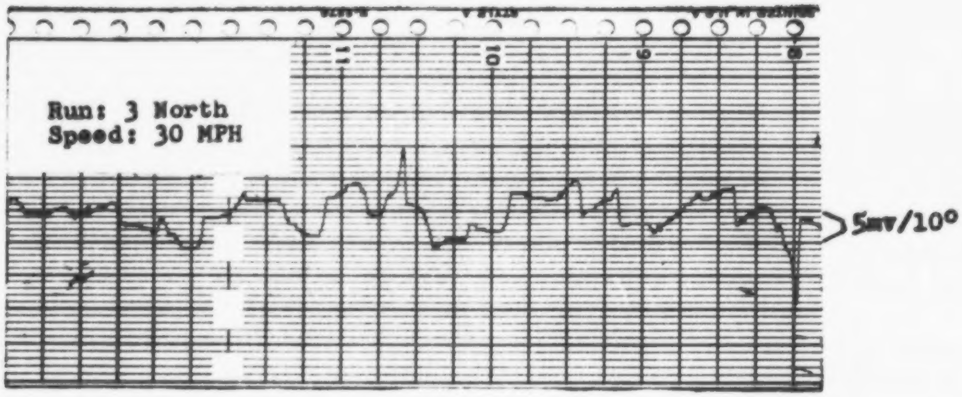
Records of steering wheel movements were taken concurrently with those for visual occlusions, registered on a Rustrak Series 400 Recorder. Input to the recorder was from a potentiometer, with independent power supply, coupled by means of a friction wheel to the steering wheel hub. The chart speed was calibrated at 1.69 mm/sec., thus permitting identification of reversals occuring at minimum intervals of 250 milliseconds. The data were recorded as an analog trace on a continuous graph calibrated at 1 mv intervals. The scale ranged from -50 mv, and a 1 mv deflection on the graph represented a 2 degrees turn of the wheel. Figure 27 shows portions of a record for one subject in runs at 30 and 50 mph, under the CO condition.

In this analysis, steering wheel reversals were operationally defined as deflections of the steering wheel of 2-9 degrees in magnitude, and 10 degrees or greater, when accompanied by a change in directional input to the wheel. The choice of these values was determined partially on the basis of previous research (Platt, 1963) and in consideration of vehicle and occlusion test constraints. Deflections less than 2 degrees were ignored, since these smaller deflections represented changes within the "slack" of the steering mechanism, and would not cause directional changes of the vehicle. Reversals of 10 degrees or greater were included to represent relatively large corrective changes in vehicle direction. Because of the "error free" performance demanded by the driving test design, reversals of 20 to 25 degrees represented the practical maximum upper limit of deflections, since such deflections would cause the vehicle to cross the lane line and end a particular run.

Subject: WF

Dec. 8, 1972

CO: 17% COHb



Subject: WF

Dec. 8, 1972

CO: 17% COHb

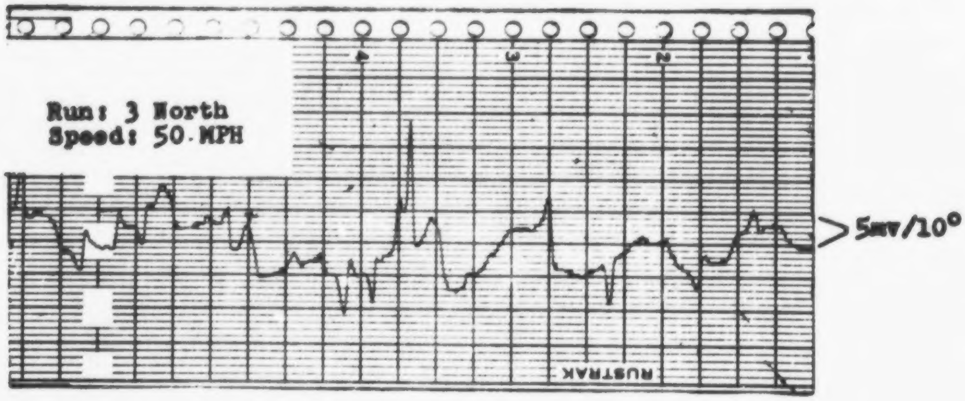


Chart Speed: 1.69 mm/sec.   Resolution: 250 milliseconds by 2 degrees.

Figure 27. Sample records of steering wheel reversals of one subject driving with 17% COHb at 30 and 50 miles per hour.

The data were treated statistically by analysis of variance. These analyses were made independently for frequencies of reversals of the two magnitude ranges for both 30 and 50 mph, with data standardized for time of run and distance of roadway travelled for CO vs. control conditions, as below:

	Reversals	Speed	Condition	Standardization
1.	_2° 10° reversals	30 mph	CO vs. No-CO	distance
2.	_10° reversals	30 mph	CO vs. No-CO	distance
3.	_2° 10° reversals	50 mph	CO vs. No-CO	distance/time
4.	_10° reversals	50 mph	CO vs. No-CO	distance/time
5.	_2° 10° reversals	30 mph	CO vs. No-CO	time
6.	_10° reversals	30 mph	CO vs. No-CO	time

Data were standardized for distance of roadway by computing the length of the record to be analyzed as a function of a known chart speed and known vehicle velocities over a fixed length of roadway. As a result, all distance analyses indicate frequencies of reversals for 1.12 mile segments of roadway. Data standardized for time were computed to reflect frequencies of reversals accumulated at 30 mph during the same period of time as those at 50 mph. These analyses, standardized for time, indicate frequencies of reversals for 1.33 minutes of run time. The analyses were based on the data for individual subjects for each run, rather than means, to take advantage of the greater statistical power of this approach.

The analyses of variance indicated highly significant intra- and inter-subject variability ($P < .01$) and negligible changes in variability associated with CO administration. In only two of these analyses was an order effect apparent. In these the significance level was $P < .05$. The interpretation of the analyses is that carbon monoxide at the level of 17% COHb does not differentially affect the frequency of steering wheel reversals.

Percent COHb versus CO Pressure (APPENDIX A)

The following table shows the percentage saturation of the hemoglobin with CO at various alveolar pressures of CO, calculated from the Haldane formula $\frac{\%\ COHb}{\%\ O_2Hb} = \frac{230(pCO)}{pO_2}$. The figure 230 has been used rather than Haldane's original value of 210 because recent work indicates that 230 is more nearly correct. The alveolar O_2 pressure is assumed to be 98 mm Hg, which is the generally accepted figure for sea level.

% COHb	PPM	% Atmosphere	mm Hg
0.87	5	0.0005	0.0038
1.73	10	0.001	0.0076
3.45	20	0.002	0.0152
5.05	30	0.003	0.0248
6.63	40	0.004	0.0304
8.16	50	0.005	0.0380
9.63	60	0.006	0.0456
11.08	70	0.007	0.0532
12.46	80	0.008	0.0608
13.80	90	0.009	0.0684
15.11	100	0.010	0.0760
16.37	110	0.011	0.0836
17.60	120	0.012	0.0912
18.78	130	0.013	0.0988
19.95	140	0.014	0.1064
21.05	150	0.015	0.1140
22.15	160	0.016	0.1216
23.23	170	0.017	0.1291
24.26	180	0.018	0.1368
25.24	190	0.019	0.1442
26.22	200	0.020	0.1520

APPENDIX B

Medical Questionnaires Used in Subject Selection

Standard Form 89
(Rev. March 1965)
Bureau of the Budget
Circular A-32

REPORT OF MEDICAL HISTORY

89-106-02
BOB Approval No. 80-R158

THIS INFORMATION IS FOR OFFICIAL USE ONLY AND WILL NOT BE RELEASED TO UNAUTHORIZED PERSONS

1. LAST NAME—FIRST NAME—MIDDLE NAME	2. GRADE AND COMPONENT OR POSITION	3. IDENTIFICATION NO. AND SSAN
4. HOME ADDRESS *(Number, street or RFD, city or town, State and ZIP Code)*	5. PURPOSE OF EXAMINATION	6. DATE OF EXAMINATION

7. SEX	8. RACE	9. TOTAL YEARS GOVERNMENT SERVICE MILITARY	CIVILIAN	10. AGENCY	11. ORGANIZATION UNIT

12. DATE OF BIRTH	13. PLACE OF BIRTH	14. NAME, RELATIONSHIP, AND ADDRESS OF NEXT OF KIN

15. EXAMINING FACILITY OR EXAMINER, AND ADDRESS	16. OTHER INFORMATION

17. STATEMENT OF EXAMINEE'S PRESENT HEALTH IN OWN WORDS *(Follow by description of past history, if complaint exists)*

18. FAMILY HISTORY

RELATION	AGE	STATE OF HEALTH	IF DEAD, CAUSE OF DEATH	AGE AT DEATH
FATHER				
MOTHER				
SPOUSE				
BROTHERS				
AND				
SISTERS				
CHILDREN				

19. HAS ANY BLOOD RELATION *(Parent, brother, sister, other)* OR HUSBAND OR WIFE

YES	NO	*(Check each item)*	RELATION(S)
		HAD TUBERCULOSIS	
		HAD SYPHILIS	
		HAD DIABETES	
		HAD CANCER	
		HAD KIDNEY TROUBLE	
		HAD HEART TROUBLE	
		HAD STOMACH TROUBLE	
		HAD RHEUMATISM *(Arthritis)*	
		HAD ASTHMA, HAY FEVER, HIVES	
		HAD EPILEPSY *(Fits)*	
		COMMITTED SUICIDE	
		BEEN INSANE	

20. HAVE YOU EVER HAD OR HAVE YOU NOW *(Place check at left of each item)*

YES	NO	*(Check each item)*	YES	NO	*(Check each item)*	YES	NO	*(Check each item)*	YES	NO	*(Check each item)*
		SCARLET FEVER, ERYSIPELAS			GOITER			TUMOR, GROWTH, CYST, CANCER			"TRICK" OR LOCKED KNEE
		DIPHTHERIA			TUBERCULOSIS			RUPTURE/HERNIA			FOOT TROUBLE
		RHEUMATIC FEVER			SOAKING SWEATS *(Night sweats)*			APPENDICITIS			NEURITIS
		SWOLLEN OR PAINFUL JOINTS			ASTHMA			PILES OR RECTAL DISEASE			PARALYSIS *(Inc. infantile)*
		MUMPS			SHORTNESS OF BREATH			FREQUENT OR PAINFUL URINATION			EPILEPSY OR FITS
		COLOR BLINDNESS			PAIN OR PRESSURE IN CHEST			KIDNEY STONE OR BLOOD IN URINE			CAR, TRAIN, SEA, OR AIR SICKNESS
		FREQUENT OR SEVERE HEADACHE			CHRONIC COUGH			SUGAR OR ALBUMIN IN URINE			FREQUENT TROUBLE SLEEPING
		DIZZINESS OR FAINTING SPELLS			PALPITATION OR POUNDING HEART			BOILS			FREQUENT OR TERRIFYING NIGHTMARES
		EYE TROUBLE			HIGH OR LOW BLOOD PRESSURE			VD—SYPHILIS, GONORRHEA, ETC			DEPRESSION OR EXCESSIVE WORRY
		EAR, NOSE OR THROAT TROUBLE			CRAMPS IN YOUR LEGS			RECENT GAIN OR LOSS OF WEIGHT			LOSS OF MEMORY OR AMNESIA
		RUNNING EARS			FREQUENT INDIGESTION			ARTHRITIS OR RHEUMATISM			BED WETTING
		HEARING LOSS			STOMACH, LIVER OR INTESTINAL TROUBLE			BONE, JOINT, OR OTHER DEFORMITY			NERVOUS TROUBLE OF ANY SORT
		CHRONIC OR FREQUENT COLDS			GALL BLADDER TROUBLE OR GALL STONES			LAMENESS			ANY DRUG OR NARCOTIC HABIT
		SEVERE TOOTH OR GUM TROUBLE			JAUNDICE			LOSS OF ARM, LEG, FINGER, OR TOE			EXCESSIVE DRINKING HABIT
		SINUSITIS			ANY REACTION TO SERUM, DRUG OR MEDICINE			PAINFUL OR "TRICK" SHOULDER OR ELBOW			HOMOSEXUAL TENDENCIES
		HAY FEVER			HISTORY OF BROKEN BONES			BACK TROUBLE OF ANY KIND			PERIODS OF UNCONSCIOUSNESS
		HISTORY OF HEAD INJURY									
		SKIN DISEASES									

21. HAVE YOU EVER *(Check each item)*

		WORN GLASSES—CONTACT LENS			ATTEMPTED SUICIDE
		WORN AN ARTIFICIAL EYE			BEEN A SLEEP WALKER
		WORN HEARING AIDS			LIVED WITH ANYONE WHO HAD TUBERCULOSIS
		STUTTERED OR STAMMERED			COUGHED UP BLOOD
		WORN A BRACE OR BACK SUPPORT			BLED EXCESSIVELY AFTER INJURY OR TOOTH EXTRACTION

22. FEMALES ONLY: A. HAVE YOU EVER—

		BEEN PREGNANT
		HAD A VAGINAL DISCHARGE
		BEEN TREATED FOR A FEMALL DISORDER
		HAD PAINFUL MENSTRUATION
		HAD IRREGULAR MENSTRUATION

B. COMPLETE THE FOLLOWING:

	AGE AT ONSET OF MENSTRUATION
	INTERVAL BETWEEN PERIODS
	DURATION OF PERIODS
	DATE OF LAST PERIOD

QUANTITY ☐ NORMAL ☐ EXCESSIVE ☐ SCANTY

23. HOW MANY JOBS HAVE YOU HAD IN THE PAST THREE YEARS?	24. WHAT IS THE LONGEST PERIOD YOU HELD ANY OF THESE JOBS? MONTHS	25. WHAT IS YOUR USUAL OCCUPATION?	26. ARE YOU *(Check one)* ☐ RIGHT HANDED ☐ LEFT HANDED

YES	NO	CHECK EACH ITEM YES OR NO. EVERY ITEM CHECKED "YES" MUST BE FULLY EXPLAINED IN BLANK SPACE ON RIGHT
		27 HAVE YOU BEEN REFUSED EMPLOYMENT OR BEEN UNABLE TO HOLD A JOB BECAUSE OF A. SENSITIVITY TO CHEMICALS, DUST, SUNLIGHT, ETC.
		B. INABILITY TO PERFORM CERTAIN MOTIONS
		C. INABILITY TO ASSUME CERTAIN POSITIONS
		D. OTHER MEDICAL REASONS *(If yes, give reasons)*
		28 HAVE YOU EVER WORKED WITH RADIOACTIVE SUBSTANCE?
		29 DID YOU HAVE DIFFICULTY WITH SCHOOL STUDIES OR TEACHERS? *(If yes, give details)*
		30 HAVE YOU EVER BEEN DENIED LIFE INSURANCE? *(If yes, state reason and give details)*
		31 HAVE YOU HAD, OR HAVE YOU BEEN ADVISED TO HAVE, ANY OPERATIONS? *(If yes, describe and give age at which occurred)*
		32 HAVE YOU EVER BEEN A PATIENT *(committed or voluntary)* IN A MENTAL HOSPITAL OR SANITORIUM? *(If yes, specify when, where, why, and name of doctor, and complete address of hospital or clinic)*
		33 HAVE YOU EVER HAD ANY ILLNESS OR INJURY OTHER THAN THOSE ALREADY NOTED? *(If yes, specify when, where, and give details)*
		34 HAVE YOU CONSULTED OR BEEN TREATED BY CLINICS, PHYSICIANS, HEALERS, OR OTHER PRACTITIONERS WITHIN THE PAST 5 YEARS? *(If yes, give complete address of doctor, hospital, clinic, and details)*
		35 HAVE YOU TREATED YOURSELF FOR ILLNESSES OTHER THAN MINOR COLDS? *(If yes, which illnesses)*
		36 HAVE YOU EVER BEEN REJECTED FOR MILITARY SERVICE BECAUSE OF PHYSICAL, MENTAL, OR OTHER REASONS? *(If yes, give date and reason for rejection)*
		37 HAVE YOU EVER BEEN DISCHARGED FROM MILITARY SERVICE BECAUSE OF PHYSICAL, MENTAL, OR OTHER REASONS? *(If yes, give date, reason, and type of discharge: whether honorable, other than honorable, for unfitness or unsuitability)*
		38 HAVE YOU EVER RECEIVED, IS THERE PENDING, OR HAVE YOU APPLIED FOR PENSION OR COMPENSATION FOR EXISTING DISABILITY? *(If yes, specify what kind, granted by whom, and what amount, when, why)*

WARNING A FALSE OR DISHONEST ANSWER TO ANY OF THE QUESTIONS ON THIS FORM MAY BE PUNISHED BY FINE OR IMPRISONMENT (18 U.S.C. 1001)

I CERTIFY THAT I HAVE REVIEWED THE FOREGOING INFORMATION SUPPLIED BY ME AND THAT IT IS TRUE AND COMPLETE TO THE BEST OF MY KNOWLEDGE
I AUTHORIZE ANY OF THE DOCTORS, HOSPITALS, OR CLINICS MENTIONED ABOVE TO FURNISH THE GOVERNMENT A COMPLETE TRANSCRIPT OF MY MEDICAL RECORD FOR PURPOSES OF PROCESSING MY APPLICATION FOR THIS EMPLOYMENT OR SERVICE

TYPED OR PRINTED NAME OF EXAMINEE	SIGNATURE

39. PHYSICIAN'S SUMMARY AND ELABORATION OF ALL PERTINENT DATA *(Physician shall comment on all positive answers in items 20 thru 38)*

TYPED OR PRINTED NAME OF PHYSICIAN OR EXAMINER	DATE	SIGNATURE	NUMBER OF ATTACHED SHEETS

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Appendix B (cont.)

Confidential

Guggenheim Center for Aerospace Health and Safety
Harvard School of Public Health
665 Huntington Avenue
Boston, Massachusetts 02115

SMOKING:

1. Do you smoke? Yes_____ No_____
2. If yes, Cigarettes_____ Cigars_____ Pipe_____
3. If cigarettes, how many packs do you smoke per day? _____

ALCOHOL:

1. Do you drink alcoholic beverages? Yes_____ No_____
2. How much do you drink? ____________________ per day

____________________ per week

____________________ per month

DRUGS AND MEDICATION:

1. Do you take any pills, drugs, or medication frequently or regularly? Yes_____ No_____
2. If yes, what kind? ______________________________________

____
Signature

____
Name (please print)

____
Street Address

____
Experimenter's Signature

____
City State Zip Code

____
Date

____
Tel. No.

APPENDIX G

Confidential

Guggenheim Center for Aerospace Health and Safety
Harvard School of Public Health
665 Huntington Avenue
Boston, Massachusetts 02115

CONSENT FORM: CARBON MONOXIDE STUDIES

1. I agree to participate in the study "The Effects of Low Levels of Carbon Monoxide on Driver RelatedVisual Tasks." For this study I will be present for six experimental sessions and receive $150.00 for my participation.

2. I understand that three of the sessions will be conducted in the laboratory at the Harvard School of Public Health, and that three of the sessions will be conducted while driving an automobile on a test track. During these sessions small amounts of blood will be withdrawn from me periodically.

3. I further understand that I will inhale gas mixtures which will give carboxyhemoglobin levels of 6%, 11% and 17%, and agree to remain with the experimenters for a period of time determined by the experimenters after each session.

4. I acknowledge that I have a valid driver's license and agree to have it in my possession at all times during the study.

5. I further acknowledge that at any time I may withdraw from this study upon notification to the experimenters. I also acknowledge the right of the experimenters to terminate my participation at any time.

Signature

Name(please print)

Street Address

Experimenter's Signature

City State Zip Code

Date

Tel. No.

APPENDIX D

DATA ON UPTAKE OF CARBON MONOXIDE (CO)

NAME	DATE	Inspired CO (ppm)	Exposure (min.)	Final % COHb	Initial % COHb	△ COHb	COHb/60 min
L. D.	May 6	300	73	5.2	2.0	3.2	2.7
	May 11	715	65	9.6	1.3	8.3	7.6
	May 19	715	78	16.5	2.2	14.3	11.2
K. G.	May 4	700	50	8.7	4.6	4.1	4.9
	May 6	300	45	5.3	4.7	0.6	0.7
	May 13	720	85	15.7	6.4	9.3	6.4
D. H.	May 7	300	55	6.1	3.4	2.7	2.4
	May 12	715	69	14.6	2.2	12.4	10.8
	May 17	720	74	16.2	2.1	14.1	11.9
P. L.	May 18	510	58	7.7	1.1	6.6	6.9
	May 26	715	52	10.6	1.7	8.9	10.2
	June 1	690	82	16.2	0.0	16.2	12.3
B. M.	May 18	510	44	7.2	1.8	5.4	7.2
	May 26	720	60	13.3	1.7	11.5	11.5
	June 1	715	69	17.3	0.8	16.5	14.4
W. M.	May 11	715	85	13.3	2.2	11.1	7.8
	May 20	510	39	8.2	1.3	6.9	10.7
	May 27	715	62	15.3	0.0	15.3	4.8
M. M.							
	May 12	715	78	12.1	1.3	10.8	8.4
	May 24	720	86	18.6	1.2	17.4	13.1
T. T.	May 13	315	65	6.4	2.0	4.4	4.1
	May 20	720	55	12.9	3.1	9.8	10.6
	May 27	720	78	19.9	2.2	17.7	13.2
J. T.	May 6	300	55	6.8	3.0	13.8	4.1
	May 17	720	82	16.9	1.4	15.5	11.3
	May 20	720	60	12.8	1.3	11.5	11.5
J. D.	Sept. 13	720	106	9.9	0.7	9.2	6.4
R. F.	Sept. 15	720	33	11.6	5.1	6.5	12.0
	Sept. 27	720	78	15.6	1.5	14.1	10.9
O. R.	Sept. 15	720	55	14.9	4.8	10.1	11.0
	Sept. 21	720	40	11.0	4.0	7.0	10.5

Page 2 - Data on Uptake of Carbon Monoxide (CO) APPENDIX D (continued)

NAME	DATE	Inspired CO (ppm)	Exposure (min.)	Final % COHb	Initial % COHb	Δ COHb	COHb/60 min
M. H.	Sept. 14*	720	54	13.4	0.7	12.7	13.9
	Sept. 14	720*	54	14.5	0.7	13.8	15.6
	Sept. 17	720*	63	16.1	0.8	15.3	14.5
J. C.	Sept. 20	720	77	17.3	2.9	14.4	11.3
A. V.	Oct. 1	720	63	12.0	0.3	11.7	11.2
	Oct. 6	720	74	13.5	1.3	12.2	10.0
	Oct. 13	720	96	18.0	1.3	17.7	10.7
W. F.	Oct. 14	720	49	14.0	0.9	13.1	16.1
	Oct. 21	720	59	14.6	1.4	13.2	13.4
S. P.	Oct. 14	720	42	9.5	0.8	8.7	12.7
	Nov. 5	720	78	17.5	0.4	17.1	13.3
A. C.	Oct. 15	720	24	9.2	3.0	6.2	14.3
	Oct. 19	720	64	15.8	2.5	13.3	12.5
J. B.	Oct. 15	720	37	9.6	3.5	6.1	9.8
	Oct. 19	720	74	16.0	3.0	13.0	10.7
H. A.	Oct. 20	720	37	8.6	0.2	8.4	13.4
	Oct. 26	720	75	15.0	0.3	14.7	11.7
D. W.	Oct. 22	720	50	9.6	0.8	8.8	10.6
	Oct. 26	720	93	18.6	1.0	17.6	11.5
J. L.	Oct. 29	720	48	11.3	0.6	10.7	13.2
	Nov. 2	720	75	19.2	0.6	18.6	14.9
R. Y.	Oct. 29	720	89	14.1	0.4	13.7	9.2
	Nov. 2	720	94	17.7	0.2	17.5	11.1
R. L.	Oct. 28	720	43	11.5	3.0	8.5	12.4
W. F.	Nov. 4	720	54	11.7	0.7	11.0	12.2
	Nov. 12	720	85	16.9	0.8	16.1	11.8
B. C.	Nov. 3	720	48	8.4	0.5	7.9	9.7
	Nov. 9	720	102	17.0	1.0	10.0	9.5
J. D.	Nov. 16	720	47	7.9	0.7	7.2	9.1
	Nov. 18	720	105	17.7	1.0	16.7	9.6
R. F.	Nov. 8	720	45	11.8	3.6	8.2	11.1
	Nov. 15	720	75	20.2	3.6	16.6	12.6

*Average of 2 slopes

APPENDIX E

Data on the decline of COHb while breathing air and while breathing a mixture of 99% O_2 and 1% CO_2

	AIR					OXYGEN + 1% CO_2				
	% COHb					% COHb				
Name	start	end	time	Δ	% start	start	end	time	Δ	% start
L.DiB.	10.4	9.4	35 min.	1.0	9.6%	9.4	6.1	35 min.	3.3	35.1%
	15.7	14.9	34	0.8	5.0%	14.9	7.6	67	7.3	48.9%
K.G.	8.7	7.4	40	1.3	14.9%	7.4	6.0	90	1.4	18.9%
same day	(5.0	3.6	70	1.4	28.0%					
	(3.6	1.8	115	1.8	50%					
	15.7	13.3	58	2.4	15.2%	13.3	8.3	45	5.0	37.5%
D.H.blood	14.6	11.4	65	3.2	21.9%	11.4	6.9	55	4.5	39.4%
alv	13.7	12.2	65	1.5	10.9%					
	16.2	12.6	63	3.6	22.2%	12.6	6.7	50	5.9	46.8%
P.L.	7.6	6.6	47	1.0	13.1%	7.0	4.4	53	2.6	37.1%
	11.5	10.7	58	0.8	6.9%	10.7	5.5	72	5.2	48.5%
	16.1	12.9	87	3.2	19.8%	12.9	5.9	68	7.0	54.2%
B.M.	7.3	6.8	28	0.5	6.8%	6.8	4.3	48	2.5	36.7%
	13.2	10.8	77	2.4	18.1%	10.8	5.7	57	5.1	47.2%
	17.0	15.7	36	1.3	7.6%	15.7	5.8	74	9.9	63.0%
W.M.	12.4	10.8	85	1.6	12.9%	10.8	7.5	40	3.3	30.5%
	8.2	6.3	85	1.9	23.1%	6.3	4.0	38	2.3	36.5%
	16.3	14.7	56	1.6	9.8%	15.8	5.6	88	10.2	64.5%
M.M.	11.2	9.7	60	1.5	13.3%	9.7	7.0	30	2.7	27.8%
	18.7	16.0	55	2.7	14.4%	16.0	10.7	70	5.3	33.1%
T.T.	6.4	5.7	75	0.7	10.9%	5.7	3.6	35	2.1	36.8%
	12.9	10.6	90	2.3	17.8%	10.6	4.6	65	6.0	56.6%
	19.9	15.6	72	4.3	21.6%	15.6	3.5	85	12.1	77.5%
J.T.	16.7	15.2	38	1.5	8.9%	15.2	7.8	63	7.4	48.6%
	12.8	10.8	75	2.0	15.6%	10.8	5.4	60	5.4	50%
J.D.D.	(9.9	8.2	58	1.7	17.1%					
same day	(8.2	6.5	217	1.7	20.7%					
B.F.	11.4	10.4	47	1.0	8.7%	10.4	6.0	56	4.4	42.3%
						15.6	6.5	59	9.1	58.3%
O.R.	11.5	10.9	31	0.6	5.2%	10.9	4.5	72	6.4	58.7%

APPENDIX E (continued)

Data on the decline of COHb while breathing air and while breathing a mixture of 99% O_2 and 1% CO_2

	AIR					OXYGEN + 1% CO_2				
	% COHb					% COHb				
Name	start	end	time	Δ	% start	start	end	time	Δ	% start
M.H	14.6	12.0	97 min.	2.6	17.8%	12.0	4.6	80	7.4	61.6%
	16.7	15.8	28	0.9	5.3%	15.8	5.7	85	10.1	63.9%
J.C.	16.5	15.4	32	1.1	6.6%	15.4	6.3	76	9.1	59.0%
A.V.	12.0	11.0	42	1.0	8.3%	11.5	6.0	65	5.5	47.8%
						15.9	4.5	87	11.4	71.6%
	19.0	16.7	60	2.3	12.1%	16.7	4.3	110	12.4	74.2%
G.F.blood	14.0	10.2	82	3.8	27.1%	10.2	4.4	67	5.8	56.8%
alv	13.5	11.6	82	1.9	14.0%	11.6	4.7	67	6.9	59.4%
alv	17.2	15.7	35	1.5	8.7%	15.7	5.4	78	10.3	65.6%
S.P.alv.	12.9	11.3	38	1.6	12.4%	11.3	5.1	54	6.2	54.8%
alv.	19.0	16.8	24	2.2	11.5%	16.8	5.0	80	11.8	70.2%
A.C.alv.	11.2	10.6	27	0.6	5.3%	10.6	4.3	73	6.3	59.4%
alv.						12.8	4.9	100	7.9	61.7%
J.B.	12.1	9.6	67	2.5	20.6%	9.6	3.7	60	5.9	61.4%
						15.0	8.1	55	6.9	46.0%
H.A.alv.	17.7	15.6	45	2.1	11.8%	15.6	3.6	100	12.0	76.9%
D.W.						8.9	3.6	70	5.3	59.5%
	20.4	16.8	67	3.6	17.6%	16.8	5.8	70	11.0	65.4%
J.L.	12.4	10.4	42	2.0	16.1%	11.7	5.0	70	6.7	57.2%
	19.2	15.0	65	4.2	21.8%	15.0	5.0	77	10.0	66.6%
R.Y.	15.3	12.5	60	2.8	18.3%	12.5	5.3	65	7.2	57.6%
alv.	20.0	15.7	50	4.3	21.5%	15.7	5.1	80	10.6	67.5%
W.F.	11.2	10.6	24	0.6	5.3%	10.6	5.4	57	5.2	49.0%
						16.8	6.9	70	9.9	58.9%
R.L.						12.8	5.0	87	7.8	60.9%
B.C.	12.7	11.7	34	1.0	7.8%	11.7	5.0	67	6.7	57.2%
	17.9	16.7	32	1.2	6.7%	16.7	5.1	108	11.6	69.4%
J.D.	12.0	11.4	33	0.6	5.0%	11.4	5.1	75	6.3	55.2%
blood	17.7	15.3	67	2.4	13.5%	15.3	4.8	100	10.5	68.6%
R.F.	12.6	9.9	60	2.7	21.4%	9.9	3.9	84	6.0	60.6%
	20.2	16.3	60	2.9	14.3%	16.3	5.5	65	10.8	66.2%

APPENDIX F

Vehicle Specifications

Basic Vehicle Code

PH43	Fury III

Paint

EW1	White

Options

A01	Light Package
A04	Basic Group
B42	Power Disc Brakes, Special
C14	Shoulder Belts, Rear
C92	Accessory Floor Mats, Color Keyed
D34	Torqueflite
D91	Sure Grip Differential
E61	383 Cu. In. 8Cyl. 2 BBL
F13	60 Amp. Alternator
F25	70 Amp. Battery
F95	Calibrated Speedometer
G21	Clear Glass
G31	Manual Mirror, Right
H31	Rear Window Defogger
H51	Air Conditioning
J21	Electric Clock
J24	Headlights Washer & Wiper
J55	Undercoating W/Hood Insulator Pad
N25	Engine Block Heater
N51	Max. Cooling Pkg.
N88	Automatic Speed Control
P25	Power Bucket or 50/50 Bench Seat, Left
P41	Power Door Locks
R26	Radio-AM W/Remote Stereo Tape
R32	Dual Rear Seat Speakers
R33	Microphone
S16	HD Suspension
S25	HD Shocks
S62	Tilt Steering Wheel W/Rim Blow
W25	HD Wheels

APPENDIX G

Preliminary Recorded Instructions for Subjects in Driving Tests

Following is a copy of the exact wording of the cassette recorded instructions given to all subjects in the driving experiments before their first training session. This is followed by more detailed explanations and demonstrations by the experimeter:

"As you know, you will be participating in a driving study where we are interested in your performance on an interstate type highway, and whether the small amounts of carbon monoxide which you breathe have any effect. Certainly, large effects will not be expected to occur. However, under all circumstances the primary rule will be safety first. Always follow our directives when behind the wheel. There will be three driving sessions, each on a different day.

During all driving runs, you will be required to drive to the same level of accuracy. In normal highway driving, you maintain the car within the marked lanes, only touching the lines when changing lanes. During the experiment, we will ask you to always remain within the designated lane, never touching the edges. In fact, when such a crossing occurs, we will recommence that particular run.

Now on all the experimental runs, you will be wearing this experimental helmet which will be used to obscure your view of the road (periodically). You can raise the visor by pressing the footswitch under your left foot. The observer has a safety switch which will raise the visor at any sign of trouble and also you can raise the visor at any time with one hand. In normal operation, when you depress the footswitch the visor will be raised for a half-second, and we know that this will give you enough time to get a good view of the road ahead. In order to get a good glimpse of the road, you should maintain your vision looking ahead and as far as possible focussed at a long distance even when the visor is closed. Do not look just ahead of the car, or to either side. Use two hands on the steering wheel in your normal driving position.

When you are driving with the visor closed, you will begin to be more and more uncertain of the car's position. You should develop the technique of only allowing uncertainty to a level where the car can be kept within the marked lane. You can then "refresh" your view of the road by taking another glimpse. Different speeds should require different rates of viewing so you should change your viewing rate to match the conditions of the particular run. Try to avoid sudden movements of the steering wheel in order to stay within the lane by setting up a smooth rhythm of performance. Remember you are in no sense competing with other subjects; we want you to do as well as you can and yet yield consistent, non-erratic performance.

Any questions ?"

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